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Education, research and partnerships in Agri-Food in a global and connected world

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Overview

In recent years, governments around the world have again realized that food and nutrition security is one of the most pressing issues facing global society today and even more so in the coming decades. This awareness crystallized during and after the food prices crisis in 2008. Raising agricultural productivity in a sustainable way is the main challenge, especially in those regions where food security is at stake today. The question is this: how, given environmental constraints, limited resources, depleting aquifers in several regions and a changing climate, can we build a global food system fit to feed more than nine billion people by 2050, and possibly up to 11 billion in 2100? Even today, with all that has been achieved, one in nine people are undernourished.

Though the obstacles to improving agricultural productivity may vary according to context, the approach that must be taken is global. Each individual innovation represents only an incremental improvement, but in combination with others and in the right context, they can become transformative. Agricultural production exists within a complex environment, encompassing science, society, industry and government. Therefore interdisciplinary, landscape-scale initiatives must be developed, and applied in partnership with all the actors involved.

As well as the availability of food, it is also necessary to have a balanced and regionally-appropriate focus on the other two elements of food and nutrition security: access and utilization. This makes it all the more important to work within the framework of agri-food systems to solve these important societal problems. I will mainly discuss the first component in relation to agronomic research. However, scientists have to work together to focus on and ensure the use of proper production tools for specific environments and contexts (in relation to access with logistics scientists and socio-economists), also considering the contribution of suitable crop nutrient content and composition to healthy diets.

The task of enhancing food availability involves several components. Of course, a major component is enhanced productivity. That is a core part of the work of agronomists. But other aspects should not be forgotten: such as non-land use, the avoidance of losses and waste (now 30 percent) and the development of alternative protein sources. Besides that, systems approaches are needed to embed the work in frameworks at higher scales: the bio-based economy and ecosystem services (e.g. water supply). These are what we call landscape approaches and as a result our work takes place at different scales: from gene to landscape. For an overview see Kropff et al. (2013).

In order to create agricultural innovation systems capable of having a transformative impact on agriculture at a global scale, research must become an integral part of the innovation processes, connecting all relevant stakeholders in co-innovation processes. This increasingly takes place within public private partnerships (PPPs). Within these processes, education plays a crucial role in training the leaders, designers, managers and policy makers of the future based on the needs of industry and cutting-edge of research.

Sustainably enhancing productivity

Yield gap and sustainable intensification

If the world population is set to grow, it stands to reason that more food must be produced, while it is also clear that this must be done while making better use of the resources available. Below the macro scale, agri-food systems in different areas in the world face very different challenges to be overcome. Even climate change, often discussed in global terms, is expected to have highly variable effects from one locality to the next. Yet by analyzing this situation, it is possible to see that the way forward for agricultural research is universal across all contexts, and best approached from a global perspective.

For those areas of Africa, Asia and Latin America that have not fully participated in the green revolution, there is still an opportunity to close existing yield gaps, i.e. the difference between actual yields and those that we know are possible: the yield potential that is determined by the variety, radiation and temperature. Yield gaps exist in most countries, ranging from almost negligible in the Netherlands to 90 percent in many African environments.

The yield potential of a variety in a specific environment is well defined, and can be calculated with good accuracy using eco-physiological simulation models. In the concept designed by CT de Wit in the 1980s, water and nutrients are yield-reducing factors, so that the so-called attainable yields (water and/or nutrient limited) can be calculated using the proper water and nutrient balance models. This is difficult to parameterize using detailed inputs from the local agro-ecological environment. On top of that we have yield reducing factors: pests, diseases and weeds. With models scenarios can be simulated to arrive at the actual yield. This understanding is based on the backbone of genotype, environment and management (G x E x M). If we understand the factors causing the so-called yield gap, improved management can help to increase yields. As improved management options have to be carefully developed and disseminated in each context, this process is known as sustainable intensification, making use of precision techniques as far as possible, both in low-yielding systems and high yielding systems (see review in van Ittersum et al., 2002).

When we look at the statistics and calculated genetic gains, it is surprising that annual yield increases have been pretty similar across regions and constant over time since the green revolution; some 70 kg of grain per hectare each year. Many hurdles must be overcome to increase productivity, such as the access to appropriate knowledge, improved seed with the desired qualities, markets and agricultural inputs by small-scale farmers in varying ecological and socio-economic environments, along with the need to improve national infrastructure and research capacities. It is also crucial to understand why farmers adopt new technologies at different rates and experience varying levels of success, while special care must be taken to include disadvantaged groups, women and youth.

For the major food exporters such as Australia that form the backbone of the global food system, yields tend to be much closer to what is possible to achieve with current knowledge and technologies. In irrigated areas we can seek the potential yield, while in rainfed or water-constrained areas it is the attainable yield that must be sought. There are some amazing examples of what can be achieved. Irrigated rice yields in the Yanco area go up to 15 t/ha compared to 7 and 10 t/ha in tropical wet and dry seasons. Just as a result of temperature and radiation. In the Netherlands, farmers harvest up to 12 t/ha of wheat, when it had long been assumed that yield potential was 10 t/ha. This is similar to the best farm yields that are already achieved here, in Tasmania.

At the global scale however, there has been a general stagnation of yields that has proven difficult to address, as yields approach the maximum potential, or the maximum attainable yield in rainfed areas. Globally, we also find challenges common to most environments that force us to take new directions and ensure that agricultural production is made sustainable. These include overcoming the unsustainable use of dwindling water supplies, managing the increased pressure from urbanization and environmental degradation of arable land.

In most continents yields of the main cereal crops have grown at rates of 70kg/ha/yr since the introduction of the semi-dwarf varieties in the 1960's. However, in Africa, yields have not shown these green revolution rates but remained more or less stable at 10% of the potential yield with the possible exception of rice where a recent analysis of FAO statistics revealed a small discontinuity in rice yield increases also in the order of 70 kg/ha/yr. However, for other crops we are still waiting for that moment where the conditions are in place for yields to begin the steep rise that we know is possible. This is a major challenge for agricultural research today that must be supported by investment in better governance systems and institutions for technology adoption.

In countries with smaller yield gaps, we see yield increases flattening off. That indicates that the breeders are not raising the yield potential and most farmers have maximized or hopefully optimized their practices. Science will have to venture into new areas of research in order to sustainably increase productivity.

Today, there is vast investment worldwide in photosynthesis research to enhance yield potential, through reduced respiration, better light capture or different pigments. There is even work underway to introduce C4 photosynthesis in C3 species.

However, leaps forward in agricultural science will not be enough to jumpstart a new era of progress: they must be coupled with policy-level changes, a reimagining of the relationship between agricultural research and industry, and further investment in human resources.

System-level approaches

The complexity of food systems means that innovations must be sought at all levels of food production, from the seed, to the farm, ecological, market, policy and research levels. This also means uniting many different scientific disciplines, and pursuing system-level approaches involving many different kinds of actors, in order to transform the capacity of agricultural systems to sustainably intensify production, while making it more market-oriented by linking consumer preferences to breeding activities. In this way, breeding becomes a systems activity, focused not on individual traits but on finding the right combinations of traits for each variety according to context and environment.

Farming systems are complex and subject to change; it is necessary to possess an understanding of dynamics at the landscape level in order for researchers and policymakers to stimulate positive changes in different regions. Several models have been developed for optimization studies and scenario studies at the regional level. The approaches developed by van Ittersum et al. (2008) make use of models that operate at different levels of integration: the crop level, the cropping system level, the landscape level and the regional/national level. Using multiple goal analyses, it is possible to analyze the effect of changes in farming systems for different decision parameters such as subsidies, labor costs, farm size etc. It would be of great benefit for policymakers and scientists to collaborate based on the insight from such models.

Scientists at both Wageningen and CIMMYT are working and at times collaborating on approaches for complex adaptive systems. In addition to thinking about dynamics of farming systems at different levels, an important development in farm systems thinking also takes into account the temporal level. Systems theories such as those developed by Scheffer on critical transitions and tipping points can be used to understand behaviors in natural systems (Scheffer, 2009). One collaboration between Wageningen and CIMMYT is exploring the factors, synergies and tradeoffs that determine the trajectories of important indicators of sustainable intensification in three different agro-ecosystems around the world, also using a participatory, goal-oriented approach (the ATTIC project, see below).

Gender studies is another critically important component of socioeconomics to help understand behaviors within farming systems. Groundbreaking work is underway within the CGIAR, with CIMMYT playing a key role, to develop tools to integrate gender understandings in the research and design process, examining the factors governing women's agency within agricultural innovation using an opportunity structure framework such as that developed by the World Bank (for example see Boudet et al., 2013). This global study, known as Gennovate, will involve interviews and focus groups with farmers in approximately 100 countries.

An urgent example of the need to adopt a systems-level approach is the prospect of climate change. The challenge to reliably realize yield gains of more than 1.5 percent per annum is heightened by expected temperature increases in most producing areas coupled with more erratic weather conditions; more floods heatwaves and droughts. The risks are especially high in the tropical and sub-tropical regions that are home to most of the world's undernourished, and where future population increases will be greatest. However, this is also a particular challenge for Australia that has amongst the most variable climates in the world.

This means that climate change poses a whole-system challenge at all scales, from the farmer deciding on the optimal crop management strategy to the stress and uncertainty placed on regional food systems. New agricultural technologies and practices must be developed in order to mitigate the negative impacts on productivity, but resilient agricultural systems must also be designed to be more adaptable at a systemic level. This is the triple win of enhanced food security, mitigation and adaptation.

There is international recognition that not only must the germplasm and deployment pipeline take account of the systemic changes wrought by climate change, but that agronomists should also adopt a climate smart agriculture (CSA) approach. Many agronomists see continuity with established practices such as precision farming that also lie at the core of CSA, however climate smart agriculture is a system-level approach that offers important perspectives, introduces an added degree of foresight and emphasizes important avenues for research.

An interesting example is one of my studies showing that good rice management practices, ensuring that the sink is suitable for the grain filling period, strongly reduces emissions of methane, a strong contributor to climate change (van der Gon et al., 2002). On the other hand, a recent inquiry from scientists at CIMMYT into the true extent of soil carbon capture potential of zero-tillage conservation agriculture practices has generated some debate (Powlson et al., 2014).

Agri-food transformations for impact

Previous agricultural transformations, such as the green revolution, have ensured a growth of agricultural production that matched population growth. But we are still left a world in which billions of people suffer health problems due to insufficient food, inadequate nutrition or poor diet. Measures must therefore also be taken to ensure equality of access to food, and the resilience of the global food system to shocks such as those that caused the food crisis of 2006-2007. Losses throughout the supply chain in the developing world, and waste in the developed world, are considered to account for a third of food production (FAO, 2013). If it were a country, the carbon footprint of this wasted production would only be inferior to that of the U.S. and China. Measures must also be taken to address the nutritional quality of food, and the impact of changing diets on the footprint of agriculture and human health. Finally, it must be understood that agriculture, from Africa to Australia, is a business, and must be profitable and attractive for those involved.

Therefore, it is important to include the concept of agri-food systems in our understanding of agriculture as a set of complex systems working at many levels. On the one hand, we can work at the level of DNA, to that of the plant, field, ecology or landscape; on the other hand, we must consider the social dimension. Agriculture is a social practice carried out for society, from the individual, to the household, community and societal levels. Encompassing the space between agronomy and society are the agri-food sector and the policy environment. So each innovation has both an agronomic and a socioeconomic dimension, and in this innovation process it is important to work in public-private partnerships.

For example, in many African countries, agricultural development will not develop in earnest without the stimulation of a vibrant private seed sector. Elsewhere, the challenge may be to link the public and the private sector more strongly to ensure the regular deployment of new varieties, or introduce policies to facilitate international seed sharing. Such public-private partnerships are operational in Australia, while in the Netherlands they are embedded within the government's 'top sector' approach. At CIMMYT, we are in the process of intensifying our work on PPPs, for example in the international maize improvement consortia for Asia and Latin America.

More investment in research and development into agri-food systems worldwide is needed, especially for the poorest of the poor in developing countries where the needs are highest. The only way to achieve this using the relatively limited resources currently available for agricultural research in developing countries is to work within strong partnerships from the local to the international level, ensuring that research is relevant and that the innovations created are put to good use in the right context.

Wageningen and CIMMYT: Working in networks to achieve food security

International, interdisciplinary approaches

The strategies of both Wageningen UR and the International Maize and Wheat Improvement Center (CIMMYT) are both based on the same core concepts: scientific excellence, the need for disciplinary depth, interdisciplinary and whole-system approaches, collaboration with different partners at all levels (transdisciplinary) and the importance of working across different contexts to maximize the value and coherence of research efforts.

Wageningen is a world-leading center of excellence for academic education and research in life sciences. Wageningen works within a 'golden triangle' of government, research institution and private sector partners to create the solutions to societal problems. It has a strong international outlook, with programs and projects in over a hundred countries, and an equally international studentship and growing international faculty. It gains strength through good relations with local and national government, private sector and NGO partners, regional and international research partners, and cooperation with developing countries who can gain from knowledge exchange and capacity-building. Wageningen focuses on science for impact on science society and business (Kropff and Kalwij, 2007).

To put this integrated approach into practice, Wageningen focuses its work on a domain defined by 3 components: Society and well-being; Food, feed and bio-based production; Natural resources and the living environment. Several themes have been selected for extra investment in new developments such as synthetic biology, bio-based economy, and complex adaptive systems. Education programs focus on B.Sc., M.Sc. and Ph.D. programs as well as international capacity-building, especially in developing countries.

CIMMYT is a leading international center for research and development of maize- and wheat-based farming systems, with research covering germplasm collection, breeding and sustainable intensification, to social sciences, gender studies, foresight and economic impact analysis. Through its collaboration with research institutions, national agricultural bodies, non-government organizations, the private sector and farmers' groups, CIMMYT leads in global innovation networks for the production, dissemination and application of agricultural innovations. Through partnerships impact is realized. Through its status as one of the 15 research centers in the CGIAR and leader of the Agri-food CGIAR Research Programs (CRPs) MAIZE and WHEAT (338 and 219 partners, respectively), CIMMYT brings together this deep-rooted network to form part of a coordinated global research agenda.

For instance, germplasm from CIMMYT's Genebank is sent to nearly all areas of the world (500,000 packages per year), creating a global platform for breeding and knowledge exchange. 50 percent of the maize and wheat sown in the developing world is derived from CIMMYT germplasm. CIMMYT has 23 offices in 13 countries, projects in 38 countries, and has a workforce of 1200 hailing from over 50 countries.

Australia is one of CIMMYT's largest financial supporters. In addition to the impact in CIMMYT's target countries, a key outcome of Australia's investment in CIMMYT is the contribution of our research and development outputs to Australian farming and the Australian economy. 98 percent of all wheat grown in Australia is derived from CIMMYT wheat varieties. Hartog, a CIMMYT introduction, was grown on more than 60 percent of Australia's wheat area in the late '80s and early '90s. This represents a major contribution to increased productivity on Australian grain farms. Australian economists have estimated that CIMMYT's wheat varieties have increased the value of outputs from the Australian wheat industry by at least AU$750 million (Brennan and Quade, 2004).

Working within agri-food system networks

The CGIAR strategy for 2016-2030 creates eight agri-food CRPs, of which CIMMYT leads MAIZE and WHEAT. Recognizing a need for integrated approach, these CRPs are cross-cut by a further four global integrating programs: Nutrition and Health; Climate Change; Water, Land Soils & Ecosystems; and Policies, Institutions and Markets. In addition to orienting global research and development networks towards agri-food systems, this structure also creates greater interaction to maximize relevance, impact and efficacy.

Wageningen works within a top-sector approach set by the government of the Netherlands, working on the sectors of water and agri-food. These two top sectors (of a total of nine) are chosen not only because they are important for society in the Netherlands, but also because they areas in which Dutch research institutions and the private sector excel and collaborate to create products and innovations of global value. This three-way 'golden triangle' of knowledge institutes, the government and the private sector acts to ensure that innovations are produced and put in use to transform agri-food systems.

As the agri-food sector is essential in all countries and can be the engine of the economy in developed and developing countries, such recognition of this sector by society is important. In Australia that recognition has always been obvious, but could be further strengthened via a more explicit focus on and support for innovation platforms and public-private partnerships (PPPs) that link public and private providers with farmers and agri-food businesses. Similar approaches are also considered for emerging and developing economies.

Global partnerships for food security
Together, Wageningen and CIMMYT provide a good example of the nexus between education, research and global partnerships. One such example is the Agro-ecosystem diversity, trajectories and trade-offs for intensification of cereal-based systems (ATTIC) project. Combining expertize from both Wageningen and CIMMYT, the project employs PhD projects in Africa, Asia and Latin America to pilot new approaches to research and development that are able to account for the dynamics of socio-ecological systems. Applied within the context of CIMMYT's global innovation network, the space for innovation created by such collaborations can have a transformative impact. Both institutions are strengthened as a result, as are those with whom they work.

Australia's interaction with CIMMYT, an organization with an explicit focus on 'yield gap' countries, also exemplifies the benefits of working in global partnerships. As mentioned above, Australia's investments in CIMMYT has a high rate of return, considering that CIMMYT wheat varieties have added AU$750 million to the value of Australian wheat industry outputs. Through the partnerships leveraged by CIMMYT, Australian institutes are supporting important research into drought- and disease-tolerant varieties in Africa and Asia that will lead to further innovations at home.

Many Australian universities are providing their expertize to a project, funded by the Australian Centre for International Agricultural Research (ACIAR), to transform the Eastern Gangetic Plains, covering parts of Bangladesh, India and Nepal, into an important food-producing region. Such a transformation requires the improvement of markets, access to agricultural knowledge and services, better use of water resources and the widespread adoption of more productive and sustainable farming practices. It is important to consider the policy environment and the innovations that could be adopted by public institutions to create the conditions for success. In this case, CIMMYT is playing a coordinating role between a network of research institutions, agricultural NGOs, public institutions and the private sector. Another project with CIMMYT, supported by ACIAR, takes a similar approach to intensify maize-legume systems in eastern and southern Africa.

These global collaborations between CIMMYT, Australian institutions and other partners are key to generating multi-disciplinary and multi-sector innovations that are essential to the improvement of regional food security.

The role of education, capacity building and partnerships
In the nexus of research and collaboration in a global and interconnected world, education plays a vital role. Capacity-building and training are prioritized at CIMMYT for three reasons: firstly, they add value to the organization and the research community; secondly, they derive more value from the research produced by the organization; and finally, they generate the expertise and capacities that make innovation successful, and therefore sustainable.

Each year, CIMMYT provides 50,000 days of training to farmers, technicians and students in 21 countries, while there are 10,000 researchers and professionals worldwide known to be alumni of CIMMYT training programs. The topics of capacity-building include breeding for scientists, seed production and registration support for small- to-medium-sized seed enterprises or direct support to extension workers and farmers. In this way, CIMMYT builds capacities at all levels.

For Wageningen, education and capacity building are core activities next to research. Academic education is directly linked to academic research following the Humboldt model set for universities some 100 years ago. Research at Wageningen not only addresses fundamental scientific questions, but takes the form of applied

research with an immediate impact for clients in the government, private sector, non-governmental and research sectors. As such, the research themes pursued are responsive not only to trends in global research, but also the needs of partners from different sectors around the world. Because education is so closely linked to research at Wageningen, the students and professionals it creates are able to make valuable contributions to solving the problems facing society today.

New communications technologies offer new avenues to further increase the impact of research institutions. CIMMYT is developing electronic decision support tools for farmers that can be delivered by extension workers or directly through mobile phones. This is being linked to new remote sensing technologies to give small-scale farmers access to the kind of knowledge used by commercial farmers in the developed world.

In Wageningen we developed the philosophy of an education ecosystem with connected components and coherence. Campus education, from undergraduate to doctorate levels, is at the heart of this ecosystem. This year the first distance learning programs will start with M.Sc. programs, with distance learning courses also being used for incoming M.Sc. students. The latest development is the use of MOOCs. Wageningen launched its first online course in 1998, and now has a strategy to integrate campus and virtual education to create an international education ecosystem using massive open online courses (MOOCs). The first two MOOCs started with 40,000 students, many from the U.S., Canada and Australia. Ph.D. research and education is organized in Wageningen Graduate Schools and courses are organized with international partners.

The global university sector must play an ever-greater role in providing vitality to agricultural innovation systems. This can be achieved by providing more exchange program opportunities for students at the undergraduate and postgraduate levels, and Ph.D. projects involving supervision from partner universities and research centers such as CIMMYT. Further value can be added with partnerships in graduate schools and large international programs with a focus on impact in areas of research such as photosynthesis, big data or genomics. The research pursued at universities can represent the high end of scientific advancement, whether in pioneering new systems approaches or new genomic techniques, and partnerships with other institutions add to the value of education for students.

Concluding remarks

According to all predictions, the world must take a great step forward to meet the challenges of raising productivity, reducing resource use, adapting to climate change and creating a fairer and healthier food system. For agricultural research to step up to the challenges facing the world today, it is necessary for agricultural research and education institutes to work in global partnerships, across disciplines and contexts to harness the power of agricultural innovation to transform agri-food systems. This requires the creation and use of strong partnerships between all the stakeholders involved in agriculture, building capacities where they are most needed and creating future generations of well-trained agricultural researchers and professionals. In this global nexus of research and global partnerships, stronger investment in education must play a central role. Agronomy is clearly a central discipline in the global food water and energy nexus!

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Forage crop systems: challenges, opportunities, and technology transfer

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Abstract
Over two-thirds of all agricultural land in the USA is grasslands, with a large economic value as well as many ecosystem benefits. Forage crop systems enjoyed maximum popularity in the middle of the 20th century after the Dust Bowl era, with pastures and hay fields recognized for their soil conservation benefits. The land-grant college system provided significant funding, infrastructure, and support for a relatively large number of forage-animal scientists. Forage crop system advances ranged from fundamental research that elucidated plant processes to applied research that developed best management practices. As the country moved from a significant rural population to a mostly urban/suburban population, both federal and state support for agricultural research declined. The heterogeneous decline in support for agricultural research has been strongly correlated with the power of commodity organizations and the perception of the commodity by the agricultural community and the general public. Forage crops lack a commodity status and are the least relevant when university research and extension cuts to programs and faculty are mandated. While forage crops are a prime example of a dual purpose crop, providing both agricultural income and ecosystem services, the general public often views all conventional agriculture as unsustainable, while at the same time reluctant to pay for valuable ecosystem services. Perennial forages as biofuel crops are seen as promising for the future of forage research by some, and seen as a death blow to forage-animal scientists by others. Increased communication with stakeholders and legislators is essential to have any hope for increasing state and federal support for grassland and forage crop research.

Key words
Grazing, Plant breeding, Legume, Grass, Biomass, Conservation

Introduction

Forage crop systems are the integrated combination of animal, plant, soil, and other environmental components managed to achieve a productive agro-ecosystem (Cherney and Kallenbach, 2007). Grasslands constitute more than two-thirds of all agricultural land in the USA, with an economic value estimated at about $45 billion annually (Sanderson *et al*., 2012). Forage crops provide one half to almost all the total feed requirements of ruminants and also serve as one of the primary resources that allow effective nutrient management planning. Only 7% of the total permanent grassland is in the eastern half of the USA (Sanderson et al., 2012). Well over half the New York State crop acreage is in perennial forages. The value of field crops in NY is similar to the value of milk, and 60% of field crop value was derived from corn silage and perennial forages. Nevertheless, the value of forages is generally seen as insignificant compared to milk. Generations of forage crop researchers have focused on maximizing forage and animal production, while the challenge for the future is to increase and sustain all ecosystem services of multi-functional grasslands (Kemp and Michalk, 2005). Management to provide ecosystem benefits and economic return can be complementary, but in many cases the desired outcomes are competitive (Nelson *et al*., 2012).

Genetics and Plant Breeding Advances

Forage breeding typically starts in the public sector and moves to the private sector, only if the product has high enough value and sufficient seed production to sustain a commercial market. Genetic gains in forage species have been lower than with grain crops for several reasons. The primary reason, however, is that forage crops are not considered a commodity of significant value, and therefore forage crops and forage-animal activities lack commodity and general public support. Since there are many potential forage crop species, and forages can be used as hay, pasture, or silage, an individual breeding program can only address a small subset of these issues (Brummer *et al*., 2009). Some improvements in forage nutritional value have been documented in forages in the past (Casler and Vogel, 1999; Wilkins and Humphreys, 2003), and the authors pointed out the need to document increased animal performance to achieve rapid adoption of new cultivars.

Alfalfa is the primary forage crop to have a major commercial sector focusing on genetic improvements in the USA. A critical mass of breeders, entomologists, pathologists, and agronomists contributed to significant gains in persistence through the development of insect and disease resistances and cold and grazing tolerance (Brummer *et al*., 2009). This same critical mass of scientists contributed to the development of low-lignin alfalfa (Reddy *et al*., 2005). Forage breeding in the future will need to focus more on the environment, with a better balance between energy and protein content to minimize N excretion (Kingston-Smith and Thomas, 2003). Forage crops generally lack the capital investment required, and the genetic simplicity desired, to attempt improvements using transgenic approaches. Unlike many countries, there is little opposition to biotech traits by USA growers, with the exception of organic growers. A significant faction of the public, however, remains skeptical of transgenic crops.

Another exception to low genetic gains in forages is the rapid expansion of forages for bioenergy (Fribourg, 2008). Government policies, along with moderate interest from the general public providing venture capital, resulted in pressure on forage breeders to improve dedicated bioenergy crop traits. Many millions of dollars provided ample incentive for forage breeders to refocus on bioenergy feedstock traits, which are typically the opposite of forage quality traits. The massive infusion of capital allowed development of transgenic approaches, with advances reported recently (Casler *et al*., 2015b; Lipka *et al*., 2014; Lu *et a*l., 2013; Ramstein *et al*., 2015). Sustainable biomass feedstock research and production has also focused on the use of marginal agricultural lands, to minimize competition with food and feed crops (Stoof *et al*., 2015). Some marginal soils, however, are inappropriate for biomass harvesting, and only suited to grazing or conservation and recreational purposes (Wells et al., 2003).

Pastures

The traditional goal of pastures is to provide sufficient quantity and quality of forage to sustain a particular group of livestock and generate a profit for the farmer. Grazing research typically involves the use of herbivores, but can consist primarily of development of forage cultivars that are either more palatable or generally higher in forage quality (Casler *et al*., 2015a; Casler *et al*., 2014). Forage and grazinglands must now focus on the wider issues of ecosystem functions and ecosystem services (Lemaire *et al*., 2005). The increasing importance of multifunctionality in grasslands cannot be effectively studied with standard short-term controlled agricultural research. Yet research funding has shifted its focus to short-term commercial advantage rather than public good (Alston *et al*., 1999). Grazing researchers are simultaneously dismissed as scientifically unsophisticated and irrelevant by the fundamental scientist, and considered impractical and not relevant by the end user (Sollenberger, 2015). In reality, grazing research projects are typically long term, requiring a range of fundamental to applied science, making this research more complex than that of the typical "fundamental" research.

Forage Management

Reduced funding for applied research and extension in forages has accelerated interest in developing computer-based tools for decision making (Hannaway *et al*., 2005). Decision support computer programs for crop and livestock systems were developed starting in the early 1980's, but it was not until recently that management decision aids became readily available to farmers. For example, Cornell's forage selection tool is made up of several programs that access databases to provide forage species recommendations and take into account the specific soil type and the intended forage use. Another series of programs has been developed to estimate neutral detergent fibre composition of pure alfalfa and binary stands of alfalfa-grass in NY (Parsons *et al*., 2006). Species composition of binary mixtures can be evaluated in cell phone photos using artificial intelligence software (McRoberts *et al*., 2012). Both systems will be available soon to farmers through smart phone apps. The future is likely to include rapid development of spectral analyses of forages in the field for yield (Islam and Garcia, 2014), quality (Post *et al*., 2007), insect, and disease evaluation using unmanned aerial vehicles. It is desirable for any new decision-making tools to be farm-size neutral, allowing all farmers access to them.

Forage Crop Extension and Outreach

The goal of extension education universally is to help people improve their quality of life and maintain viable, profitable agricultural ventures (Murray, 1999). Extension education facilitates technology transfer. Technology transfer requires: 1) information generation, 2) an informed target audience, and 3)

implementation by the target audience (Undersander, 2005). In reality, extension faculty duties at USA universities range from 100% extension education responsibilities to nearly 100% information generation responsibilities, depending on the university and the region of the country.

Sollenberger (2015) suggests that we might limit our target audience to the most progressive farmers ("change agents"), and let their success extend the technology, instead of delivering the message to anyone who will listen. This strategy would focus applied research/extension efforts on successful implementation of technology on the most progressive farms, which may be the most efficient use of a small and shrinking set of forage personnel. On the other hand, forages provide great value to society and to agriculture, and the public becomes aware of forages primarily through extension education activities. Regardless of delivery method, implementation is critical.

Undersander *et al*. (2009) reported that over 65 full-time equivalent (FTE) of forage extension positions were lost across the USA from the period of 1987 to 2007. Rouquette et al. (2009) estimated that there will be a 47% decrease in forage-animal extension FTE scientists in the USA during the 20-year period from 1998 to 2018. Because forage-animal systems is a nebulous commodity, extension positions in this discipline will probably be the least likely to be considered for replacement when such positions open up.

Land-grant system and forages

The Morrill Act of 1862 and subsequent amendments funded educational institutions in the USA by granting federally-controlled land to states in order to sell it and raise funds to establish "land-grant" colleges. Their original mission was to focus on teaching agriculture, science, military science, and engineering. Coupled with these colleges, the 1887 Hatch Act created the agricultural experiment station program. For well over 100 years, scientists working at state agricultural experiment stations and land-grant colleges have conducted research to improve the quality of life for its citizens, and almost everyone agrees that the system has been very successful. Land-grant colleges became the foundation of modern USA agricultural productivity and efficiency. The success of land-grant colleges in increasing agricultural productivity lead to a rapid decline in rural population, and the land-grant system gradually became a casualty of its own success (Fribourg, 2003).

Federal support of land-grant colleges has declined substantially during the past 40 years, forcing states to provide much of the land-grant college support. In the increasingly urban states, competition from primarily urban programs claimed more tax revenues, so many states lost touch with agricultural research and became less willing to support it. By 1990, both states and the federal government were significantly reducing funding for agricultural research (Alston *et al*., 1999), encouraging scientists to compete for extramural funding sources. Traditional federal formula funds for states were gradually replaced by competitive research programs. Competitive grants are typically for relatively short-term research. Consequently, perennial forage and grassland research, which normally requires long-term research, is one of the research areas most negatively impacted by the shift away from formula funds.

Funding now has shifted from state to grant-funded areas, even though state agricultural experiment station mission statements appear to have remained intact (Rouquette et al., 2009). The shift in funding support has impacted some disciplines much more than others. One of the areas with very few extramural funding opportunities is forage crops. Faculty appointments also have gradually shifted to disciplines and commodities with the most extramural funding support, supported by vocal commodity groups and other vested interest groups. Public support for the experiment station model may eventually be undermined by faculty appointments and programmatic directions that ignore or minimize the value of providing products and technology to traditional clientele (Sollenberger, 2015).

New Funding Paradigm

To counteract the trend towards discipline-oriented research (Maplestone and Blundell, 1995), research entities have been created to attempt large, interdisciplinary research projects at regional, national, and international scales. The European Commission initiated the Joint Programming Initiative (JPI) in 2008, to increase the value of national and EU research funding through joint planning and implementation of research programs. For example, the initiative on Agriculture, Food Security and Climate Change (FACCE-JPI) brought together 21 countries to address the overlapping challenges of sustainable agriculture, food

security, and climate change, through interdisciplinary research (FACCE-JPI, 2015). Also in 2008, the National Institute of Food and Agriculture (NIFA) was formed within the USDA, to integrate scientific disciplines, as well as to integrate research, education and extension activities. While forage and grassland issues appear to be well represented in JPI programs, less than 0.2% of NIFA's nearly $800 M research and education budget has been dedicated specifically to forage and grasslands.

Impact of Funding Strategies on Forage Crop Research

The use of forage crops as cellulosic biofuel is often seen as a bright spot for the future of forage crop research. The 907 million tonnes (Billion-ton supply) of biomass that is estimated to replace 30% of USA petroleum needs (Perlack *et al*., 2005) would likely include about 15 million ha of grasslands (Undersander et al., 2009). While this could have a significant positive impact on grasslands, it could also have a potentially large negative impact on forages. Due to the lack of funds for forage crop research, many forage workers have migrated toward the more fundable issues, which are not typical agricultural production. Currently, there appears to be ongoing FTE transition from retiring forage crop researchers, who pursued funding in peripheral areas such as biomass, to newly-hired biomass researchers who will have peripheral responsibilities for forage crop research. While forage researchers constantly look for creative ways to supplement their forage research programs, biomass researchers with minor forage crop responsibilities will be much less likely to pursue forage research projects that provide limited funding support or university overhead.

Multiple authors have pointed out that although forage crops promote clean air and water, and reduced flooding and erosion, the general public is unaware of forages as a valuable commodity (Undersander et al., 2009; Rouquette *et a*l., 2009). In New York State for example, the dollar value of perennial forages exceeds the combined value of all fruit and all vegetables, excluding the environmental benefits of forage crops. Yet there are approximately 15-fold more fruit and vegetable FTE scientists at Cornell University, compared to those in forage crops. From 2008 to 2018, it was estimated that almost half of the existing forage utilization scientists in the USA will retire (Rouquette, *et al*, 2009). Unfortunately, many of these forage scientists are not being replaced.

Conclusions

Forage crops are a major renewable natural resource with significant ecosystem services in the USA but they receive virtually no recognition nor respect among University and Government administrators. Society wants farmers to adopt sustainable practices, but as of now are unwilling to pay for it. Needs assessments over the past 20 years have been relatively consistent for forage and grasslands. Forage crops and the forage-animal system are not seen as a commodity, and therefore will continue to lack commodity support. At a time when we should be returning to a more integrated forage-animal research paradigm, the future is likely to see a continued decreasing allocation of scientists to forage-animal programs. If universities hire replacements, position descriptions will focus on fundable themes that include significant indirect cost recovery. Forage researchers may be found primarily in industry in the future. It is up to us, forage researchers, to increase communication with stakeholders and legislators on the importance of forage crops to agriculture and society as a whole. We must identify "legislative champions" for forage crop systems who will advance the importance of increased state and federal funding for this unsung hero of animal agricultural systems.

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Development, participatory extension and adoption of zero tillage – the case of Syria and Iraq 2005-14

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Abstract
This paper presents experiences in an Australian-funded project which aimed to improve crop productivity, profitability and sustainability through the development and promotion of zero tillage (ZT) cropping in Iraq and Syria. As a result of the project, the area of ZT crops in Syria increased from a zero base in 2006 to 30,000 ha grown by more than 500 farmers in 2011-12. In Iraq, there was about 15,000 ha of ZT crops grown by 100 farmers in 2013-14, also from a zero base in 2006. Whilst this is only a small percentage – around 1.8% for Syria and 0.9% for Iraq - of the wheat area grown, it is considered a good foundation for on-going uptake of ZT. The success of the project can be attributed to five critical strategies: 1) recognition of problems and the need for change, 2) identification of better technology, 3) research for local verification and adaptation of ZT, 4) addressing constraints through local fabrication of ZT seeders, and 5) participatory extension to enhance ZT awareness and experience and promote ZT adoption. For the vast majority of farmers taking up the technology, ZT and early sowing resulted in cost savings, increases in grain yield, reduced environmental degradation, and improved soil quality. In surveys of Syrian wheat farmers who had adopted ZT and early sowing, yields were increased by 465 kg/ha and net incomes were boosted by $US 194/ha on average. If 80% of wheat farmers growing the ≈1.7 million hectare wheat crop in Syria used ZT this would produce an extra 630,000 tonnes of wheat worth about $US 250 million per year. Iraq has similar wheat areas to Syria and benefits from ZT might be higher due to higher wheat prices. Other crops would also benefit from ZT. Importantly for the region, the technology decreases the risk of crop failure under dry conditions and reduces the negative effects of climate change. The project is a successful example of adapting and applying Australian knowledge and skills for the benefit of partner countries that have similar agro-ecological conditions as Australia.

Key words
Zero tillage, participatory extension, early sowing, low seed rates, conservation agriculture, Iraq, Syria

Introduction

Dryland cropping in Syria and Iraq and the wider West Asia and North Africa (WANA) region is characterized by grazing, burning or harvesting of crop residues, multiple cultivations, late sowing, and high seed rates which results in high costs, limited yields, and soil erosion and degradation (Cooper *et al*. 1987, Pala *et al*. 2000, Moeller *et al*. 2014, Loss *et al*. 2015). In the dryland areas of the Mediterranean region where low and variable rainfall (250-350mm) mostly falls between October and April, cereal and legume yields are often low. In wheat, which is the major crop in the region, grain yields are commonly less than 1t/ha (Moeller *et al*. 2014, Loss *et al*. 2015), well below water-limited or attainable yields of around 4.2-6.4 t/ha (Sadras and Angus 2012). In contrast, many farmers in similar areas of Australia now approach attainable yields through the use of improved crop varieties and better agronomy (Anderson *et al*. 2005, Sadras and Angus 2006, Anderson 2010, Passioura and Angus 2010, Kirkegaard *et al*. 2014, Richards *et al*. 2014).

In Australia, a key component of better crop management has been the use of zero tillage (ZT) to sow crops early with no prior cultivation, low soil disturbance and retention of stubble. Over the last 30 years, ZT has been adopted by about 80-90% of Australian farmers (Llewellyn *et al*. 2012), who have been attracted by the better flexibility, productivity, profitability and sustainability of the ZT system. In WANA over this time, ZT has been little known, researched or adopted. This paper presents some experiences in an Australian-funded

project (2005-14) which aimed to improve crop productivity, profitability and sustainability through the development and promotion of ZT cropping in Iraq and Syria. Project partners were the International Center for Agricultural Research in Dry Areas (ICARDA) in Syria; the Ministry of Agriculture (Directorate of Agriculture, State Board for Agricultural Research) and the University of Mosul in Iraq; and the Universities of Adelaide and Western Australia and the Western Australian Department of Agriculture in Australia.

During the life of the project, ICARDA and Australian collaborators were unable to visit Iraq due to security concerns and all implementation within Iraq was undertaken by Iraqi collaborators. ICARDA was a meeting, testing and training ground for project collaborators, where work programs were planned, progress was reported, technologies were tested and adapted, and training courses were undertaken. Although not formal partners in the project, many Syrian institutions, machinery manufacturers and farmers interested in this "new" ZT technology became involved in and made a great contribution to developing, testing and promoting ZT systems and encouraging their wide adoption in Syria.

The success of the project can be attributed to five critical strategies: 1) recognition of problems and the need for change, 2) availability of better technology, 3) research for local verification and adaptation of ZT, 4) addressing constraints through local fabrication of effective, affordable ZT seeders, and 5) participatory extension to enhance ZT awareness and experience and promote ZT adoption.

Recognition of problems and the need for change

The prevailing conventional cropping system in the dryland areas of WANA has been characterized by heavy grazing or burning of crop stubbles and residues, multiple cultivations before sowing, late sowing (Dec-Jan), high seeding rates (with disc plow seeding in some areas), and little diversity in cereal-fallow or cereal-cereal rotations (Cooper *et al*. 1987, Pala *et al*. 2000, Moeller *et al*. 2014, Loss *et al*. 2015). The consequences of such a system are poor storage of soil moisture, high costs of land preparation, delayed sowing, low grain yields and profitability, water and wind erosion, soil degradation, and air pollution from burning stubbles and dust. Adding to these problems are declining rainfall and more variable weather due to climate change. At the time the project started in early 2005, Iraqi farmers and scientists recognized the need for a more productive, profitable and sustainable system, especially in light of increasing costs and reduced availability of diesel fuel and the degradation of soils.

Availability of better technology

ZT cropping with minimal soil disturbance, early sowing and retention of some crop residues was seen as a technology with great potential to increase the productivity, profitability and sustainability of cropping systems in WANA, especially given its success in Australia (Llewellyn *et al*. 2012), where the climate, soils and crops have many similarities (Loss *et al*. 2015), and in many other countries. ZT cropping can provide benefits related to the crop (early sowing, higher yield potential, and savings in time, machinery maintenance and fuel), the soil (better soil structure, higher organic matter, increased porosity, better soil-water dynamics, increased nutrient recycling, and improved trafficability), and the environment (less pollution, less erosion, and increased C sequestration). Although widely adopted around the world, ZT, strangely, was little known and unused by farmers in Iraq or Syria in 2005.

The ZT system developed and promoted by the project was based around eliminating pre-sowing cultivation and sowing seed (and fertilizer if applied) through surface residues from the previous crop into narrow (≈10-20mm) slits/furrows opened in the soil by the narrow points/tines of a ZT seeder. The conventional tillage (CT) system, used by most farmers in Syria and Iraq, involved one to three or more cultivations with mouldboard, disc or chisel plows and seeding into bare cultivated soil with a drill or disc plow seeder (Pala *et al*. 2000, Moeller *et al*. 2014, Loss *et al*. 2015, Piggin *et al*. 2015).

Research for local verification and adaptation

A field research program commenced in Syria in 2005-06 at ICARDA's station, just south of Aleppo, to test and adapt the ZT system, and compare its performance with CT systems (Piggin *et al*. 2011, Sommer *et al*. 2014, Piggin *et al*. 2015). Over 10 years, a series of experiments showed in general that:

- ZT was more productive, sustainable and profitable than CT
- all crops (wheat, barley, oats, chickpea, lentil, faba beans, field peas) performed well under ZT

- there was no need for special ZT varieties; the best ones under CT were also the best under ZT
- early sowing facilitated by ZT was more productive than late sowing
- stubble retention had little effect on crop performance, especially in early years
- low seed rates (50-100kg/ha) were more productive than high seed rates (200-300kg/ha)
- crops little grown in the Middle East (field peas, oats) performed well under ZT and can provide diversity in rotations.

Seeing and/or hearing about these trials gave researchers and farmers an interest and confidence to consider and incorporate some of the findings in demonstrations and broad-acre crops on-farm in both Syria and Iraq.

To guide users, a list of possible management options to maximize production, profitability and sustainability was developed from these and other research findings, with those considered most important in changing from CT to ZT systems highlighted in bold:

- **stop plowing**
- **don't burn stubble** – keep as much as possible on the soil surface
- **use ZT seeders** for all crops
- **if weeds are present before sowing** kill them with glyphosate
- **plant early** (late October/early November)
- use good quality seed of the best adapted varieties
- **reduce seeding rates** to 50-100kg/ha for cereals and 100-150kg/ha for pulses
- sow at the optimum depth (4-6cm)
- use the best available fertility & weed/disease/pest management
- include non-cereals in rotations if possible
- graze crop residues and stubble if needed - this doesn't cancel ZT benefits.

The project did not promote these options in any sort of fixed "package" but rather suggested farmers focus with flexibility on those components highlighted above in bold, which are important in changing from CT to ZT systems and likely to provide the greatest immediate benefits through reduced costs (fuel, labor and seed) and increased yields. Other (non-bolded) components were seen as part of good crop management in any tillage system, to be considered and used as and when required. It was recognized that some components may not be appropriate in certain situations. For example, in Syria and Iraq, and elsewhere in WANA, stubble retention is difficult because crop residues are highly valued as a stockfeed and there are few fences to control livestock, so crop residues are generally heavily utilized. Also, crop rotation is limited because wheat is the most reliable and profitable crop (partially due to government subsidies), which discourages inclusion of legumes in rotations. A flexible approach is also used in Australia, where farmers are pragmatic rather than prescriptive about the use of "ideal" conservation agriculture (CA) components as they are now commonly promoted (ZT with no soil disturbance, full stubble retention and >3 species in the rotation), and many farmers continue some strategic tillage, intensive cereal systems dominate, and partial removal of crop residues as hay or by grazing livestock is commonplace, to optimize both economic and environmental outcomes (Kirkegaard *et al*. 2014).

Simple economics suggested there could be attractive returns and savings with eliminating unnecessary cultivation, adopting ZT and early sowing, and reducing seeding rates to 50kg/ha (Table 1).

Table 1. Possible economic returns/savings in Syria with wheat grown using ZT, early sowing and a low seed rate compared to CT, late sowing and high seed rate.

Operation	Change	Return or saving /ha ($US)
Use ZT and early sowing	+ 500 kg/ha yield	$200
Stop plowing	2 → 0 times	$ 50
Reduce seeding rate	300 → 50 kg/ha	$100
Reduce seeding rate	+ 1,000 kg/ha yield	$400
Total		$750

Local fabrication of ZT seeders
A major constraint to the adoption of ZT was the lack of effective, affordable, locally-available ZT seeders. Imported ZT seeders were too large, complex and expensive for small-scale farmers, and accessing parts and maintenance locally would have been difficult. In response, the project discussed and demonstrated ZT seeding technologies with local seeder manufacturers in Syria in 2007-08 and, guided by Australian experience and engineering expertise, worked with three workshops around Aleppo to design and fabricate various ZT seeder prototypes. The first ZT seeders were 2.3m wide, with three-point-linkage mountings suitable for small tractors (60-100hp) common in the region. They had narrow points/openers (≈10-20mm), widely-spaced tines which were spring-loaded for rocky areas, and separate seed and fertilizer delivery capacity.

Following evaluation and feedback from farmers, 4m wide trailed and three-point-linkage ZT seeders with wider tine spacing for better stubble flow were also fabricated for larger tractors and more extensive cropping areas in eastern Syria and Iraq. These all worked effectively at ICARDA and in farmer fields. In an experiment with early (mid-Nov) and late (mid-Dec) sowings in 2008-09, crop establishment and yields for wheat, barley, lentil or chickpea were similar when sown with imported ZT seeders from India and Germany and the three locally-made ZT seeders. With this early success, other interested seeder manufacturers were assisted by the project to begin fabricating and marketing ZT seeders.

By 2011-12, after many improvements in materials, design and construction, there were seven local workshops making effective ZT seeders in Syria. Prices for these locally-made ZT seeders were around US$1,500 for 2.3m wide and $4,500 for 4m wide models. These were affordable for farmers and by 2011-12, 92 ZT seeders had been fabricated, of which 26 were purchased by Syrian farmers and 28 were sent to Iraq for evaluation and use in demonstration and extension programs (Table 2). Local production has greatly increased farmer access to ZT seeders.

Table 2. Number of ZT seeders manufactured in Syria 2008-09 to 2011-12.

Purchaser	2008-09	2009-10	2010-11	2011-12	Total
ICARDA	3	6	3		12
Syrian Govt.		2	2	1	5
Syrian NGOs			**1**	**5**	**6**
Syrian farmers		4	**14**	**8**	**26**
Iraq projects	4		**14**	**10**	**28**
Other countries		1	10	4	15
Totals	7	13	44	28	92

The pathway to local manufacture of ZT seeders was different in Iraq, due to the lack of operational seeder manufacturers and difficulties with security and accessing required construction materials in rural areas. After Syrian-made ZT seeders were sent to Iraq in 2008-09 and used in demonstrations and farmer fields, some innovative Iraqi farmers developed very effective ZT conversion kits (basically narrow tines and openers spaced more widely on the seeder frame) for the widely available John Shearer-type conventional seeders, which greatly increased local access to ZT seeders for demonstrations and farmers. With time, capacity for local fabrication has been developed and two manufacturers in Mosul are making effective and affordable ZT seeders, with 9 produced in 2013-14. Unfortunately, local ZT seeder fabrication has been greatly restricted by the post-2010 civil unrest in both Syria and Iraq and few are being manufactured or purchased.

Participatory extension – enhancing ZT awareness, knowledge and experience
In Syria, researchers, extension specialists, farmers and others with an interest in ZT undertook study tours to inspect and discuss research at ICARDA, visit local ZT seeder manufacturing workshops, and meet farmers involved in early testing of ZT on their own farms. These tours greatly increased awareness and knowledge of ZT cropping and ZT seeders. Some 400-600 people visited ICARDA in each of the three years from 2008-09 to 2010-11 (Table 3) which encouraged exchange of ideas and experiences with ZT between ICARDA and Iraqi/Syrian researchers, extension officers, seeder manufacturers, and farmers.

Table 3. Numbers of visitors inspecting ZT research trials at ICARDA, local seeder manufacturers and pioneer farmers.

Visitors	2008-09	2009-10	2010-11	Total
Iraqi/Syrian project scientists and farmers	100	100	80	280
Others	500	300	300	1,100
Total	600	400	380	1,380

Practical experience of growing crops with ZT was enhanced by establishing participatory ZT working groups in Syria to facilitate farmer testing of ZT on their own farms. The working groups involved ICARDA, research and extension scientists from the Ministry of Agriculture, seeder manufacturers, private industries, NGOs and farmers. The program expanded from seven to fourteen groups between 2009-10 and 2011-12. In this program, general arrangements for the ZT working groups were:

- a group was established for each location and a leader selected
- a local ZT seeder was assigned to the group
- farmers registered their interest to use the ZT seeder with the group leader
- the ZT seeder was made available to farmers without charge or payment
- the farmer was responsible for all inputs (tractor, seed, fertilizer) and sowing the crop
- the farmer was responsible for the transfer of the ZT seeder in good condition to the next farmer
- ICARDA supported some long-distance transport and major maintenance when necessary
- ICARDA and Syrian institutions provided technical and other support for the leader and group
- the group arranged farm walks, field inspections, and field days
- farmers recorded yields of their ZT crop and nearby CT fields.

Most Syrian farmers tested and adopted ZT and early sowing, and many used reduced seed rates. Very few retained significant amounts of stubble, or changed their cereal-dominated rotations. Despite this, farmers generally found yields were better with ZT and early sowing than with CT. Information collected from the farmers over the three years from 2008-09 to 2010-11 (Loss *et al*. 2014) showed that the average grain yield increases with ZT compared to CT were 0.26 t/ha (15%) for barley (number of fields = 278), 0.33 t/ha (19%) for wheat (n = 264), and 0.23 t/ha (21%) for lentil (n = 88). Along with these yield increases, significant savings in time, machinery costs and fuel were reported. These on-farm yields increases were similar to those recorded in a long-term trial at ICARDA, where the average (2008-09 to 2011-12) grain yield increases of ZT with early sowing compared to CT with late sowing were a significant 0.33 t/ha (18%) for wheat, 0.13 t/ha (20%) for chickpea and 0.14 t/ha (15%) for lentil, and a non-significant 0.30 t/ha (12%) for barley (Piggin *et al*. 2015).

The working groups held many field days and farm walks in farmer fields to inspect and discuss ZT crops and seeders. For example, in 2009-10, there were three major ZT field days on-farm in northern Syria, each attended by 300-400 people. These Syrian field days were also linked to training at ICARDA for Iraqi/Syrian scientists on participatory extension and for Iraqi/Syrian farmers on a ZT study tour. The opportunity to see ZT crops and seeders, and hear how farmers had adapted the technology to their farming operations, had a great impact on field day participants and promoted wide interest and uptake of ZT. Unfortunately, in Syria, unrest and insecurity curtailed the participatory extension program and further field days after mid-2011.

In Iraq, in a necessarily different approach to participatory development and extension, ZT technology was tested, developed and promoted through large-scale, long-term demonstrations in farmer fields comparing ZT and CT systems, planting times and seed rates. Crops were sown with Syrian-supplied or Iraqi farmer-converted ZT seeders. The program started in 2005-06 with 12 demonstration locations and additional locations were added after 2008-09 as farmer interest spread and more local seeders became available. By 2012-13, the program had expanded to 37 districts in Ninevah and 14 in the surrounding Governorates of Anbar (5), Salahaldin (4) and Kirkuk (5). Farmers were actively involved together with extension and research collaborators in the management of these demonstrations. Each year, there were regular inspections and field days, often with 40-50 scientists and farmers attending. The participatory extension program encouraged great interest in ZT amongst Iraqi farmers and, as in Syria, those wanting to try ZT on their own farms were able to get access to a ZT seeder from the project or from another farmer. In Iraq, unrest and insecurity

curtailed demonstrations and further field days after 2013-14.

Adoption

During 2005 to 2012 there was remarkable progress in the development, promotion and adoption of ZT in Syria and Iraq (Figure 1). In Syria, from a zero base in 2005-06, the area of ZT crops increased to 30,000 ha grown by 500+ farmers by 2011-12 (the last reliable figures available). Some 70-80% of this area was true adoption, where farmers owned, rented or borrowed a ZT seeder independent of the working groups. In Iraq, there was some 15,000ha of ZT crops grown by about 100 farmers in 2013-14. Whilst these areas represented only a small percentage of cropped land (1.8% and 0.9% of the 1.7 million hectares of wheat in Syria and Iraq respectively), it is considered that they form a sound foundation of experience for self-sustaining expansion of ZT.

As has been the case in many parts of the world, many Syrian and Iraqi farmers struggled to accept that crops could be grown without cultivation. The participatory ZT working groups were an excellent way to raise awareness and experience, and give farmers the confidence and opportunity to test and adopt ZT. There was much farmer to farmer learning and local ZT champions emerged from many groups. Local manufacturing of ZT seeders was critical to support expanding adoption, and the links between farmers and seeder manufacturers were very important to encourage user feedback and enable improvements in seeder design and production. It was no coincidence that ZT adoption began to accelerate after 2008-09 (Figure 1) when ZT seeders became more widely available (see Table 2) to support a major campaign of participatory extension which in turn facilitated farmers gaining experience with establishing and managing ZT crops with early sowing and low seed rates.

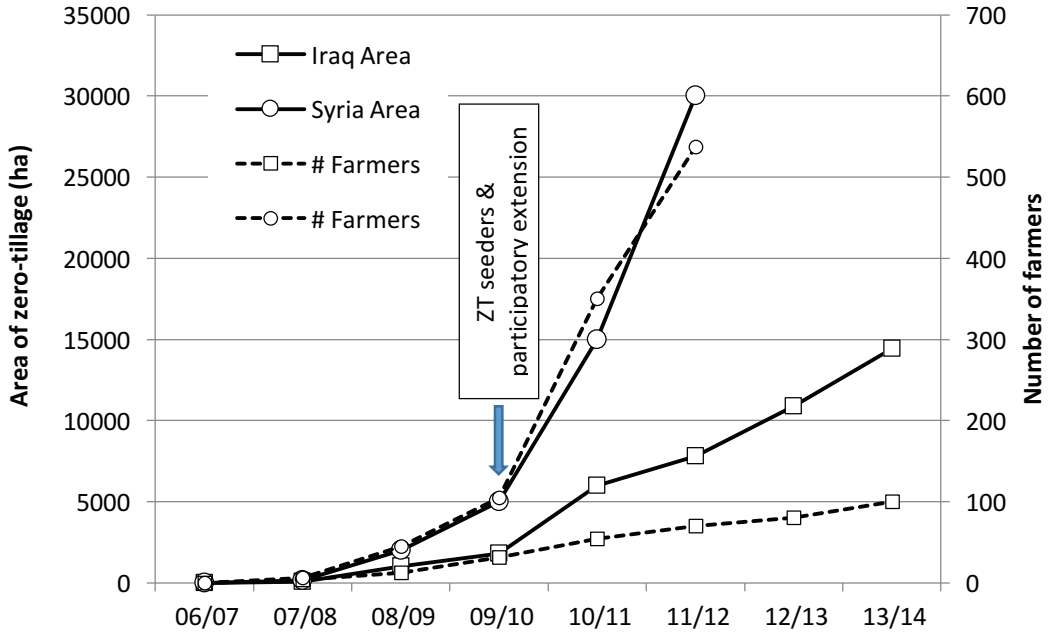

Figure 1. Area under ZT and number of farmers using ZT in Syria and Iraq (2006/14)

This success has been due in no small manner to the ongoing dedicated work to develop and promote ZT by researchers, extension specialists, farmers and manufacturers as civil unrest escalated after 2011-12 in Syria and Iraq. ZT is continuing to be popular amongst farmers because, without plowing, the requirement for increasingly scarce and expensive fuel and the risks to personal safety are both reduced with less time working in fields and transporting cultivation machinery on roads. While the overall cropping area has decreased in the past two or three years in both countries due to the civil unrest, anecdotal evidence suggests the proportion of crop sown using ZT has increased.

Economic impacts

The economic impacts of adopting ZT are potentially large. In a 2011 survey of Syrian wheat farmers who had adopted ZT (often with early sowing and lowered seed rates), on average, grain yields were increased by 465 kg/ha and net incomes by US$ 194/ha (Yigezu et al. 2014). In Syria in 2011-12, the total benefit across 30,000 ha was about $5.8 million. If 80% of farmers growing the 1.7 million hectare wheat crop in Syria used ZT (the typical levels of adoption in many parts of Australia), this would produce an extra 630,000 tonnes of wheat worth about $250 million per year at the subsidized price of $400/tonne. Iraq has similar wheat areas to Syria but benefits from ZT might be higher; the subsi-

dized price for wheat was $700/tonne in Iraq in 2011-12 before the unrest broke out. Of course other crops would also benefit from ZT. The development of seeder workshops also provides valuable business opportunities and much needed employment in rural areas. ZT could have a similar major impact on the economic productivity and food security of many WANA countries which have similar Mediterranean environments and cropping systems, reducing reliance on imports to feed their populations.

Conclusions

At the start of the project, farmers and scientists in Syria and Iraq were understandably skeptical about the possibility of growing crops without tillage but had an understanding and concern that their heavily-cultivated, conventional systems were limiting production, degrading soils and polluting the environment with dust and smoke. The research and demonstration programs in both Syria and Iraq, conducted on large plots, were central to verifying, adapting and raising awareness and understanding of ZT systems and identifying some technology options (no plowing, ZT, early sowing, low seed rates, no stubble burning) for farmers to consider, evaluate and adopt on their own farms. There was no promotion of a fixed "package" (e.g., CA); rather, flexibility was emphasized and farmers were free to choose the ZT system components they wished to use. Perhaps the most important initiative was to work with local engineering companies and innovative farmers to develop capacity to fabricate effective and affordable ZT seeders and ZT conversion kits, and provide farmers with ready access to suppliers for seeder purchase, repairs and maintenance and to receive feedback on design and performance. Success of projects promoting ZT systems can be limited if there is reliance on less well-adapted, expensive, imported seeders. The participatory extension program, involving participation in training courses, demonstrations, study tours, field days and farm walks, and providing access to a ZT seeder for interested farmers to test ZT on their own farms, was a key to increasing farmer knowledge, experience, ownership and uptake of ZT systems.

That this logical project approach brought encouraging adoption of ZT – 30,000ha by 500 farmers in Syria by 2011/12 and 15,000ha by 100 farmers in Iraq by 2013/14 – is not surprising because the technology is highly relevant to farmer concerns of low yields and resource degradation, highly compatible with existing mechanized cropping operations, and can increase wheat yields by ≈500 kg/ha and income by ≈$ 200/ha, or more, in farmer fields. Farmer surveys confirmed that project strategies such as facilitating farmer testing of ZT on-farm and participation in field days increased the probability of adoption (Yigezu *et al*. 2015). The project experience is that ZT is not scale-, soil- or crop-specific and, for farmers already growing dryland crops, ZT can be a simple alternative to CT, provided there is access to an owned, borrowed or rented ZT seeder, with adjustments e.g. herbicides, residue handling, disease management rather than major changes required to existing cropping operations. Whether adoption will expand to 80-90% of farmers over the next 20 years, and match that achieved in Australia over the last 30 years (Llewellyn *et al*. 2012), will depend, amongst other things, on the continuation of effective research, development and extension and, importantly, the cessation of unrest and violent conflict in Iraq and Syria.

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Achieving sustainable improvements in nutrient efficiency with precision agriculture

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Abstract
With the global population expected to surpass 9 billion people by 2050, sustainable increases in food production will be a necessity. A key contributor to this increase will be the use of mineral fertiliser. 4R nutrient stewardship – applying the right nutrient source at the right rate, at the right time and in the right place – is an innovative approach in fertiliser management. However, to meet the multi-dimensional goals of sustainable agriculture, appropriate performance metrics must be identified to assess the effectiveness of fertiliser management changes. One such metric is nutrient use efficiency (NUE). While 4R stewardship provides a framework that can result in improvements in NUE, implementation is greatly enhanced by the tools and technologies, associated with precision agriculture (PA). The purpose of this paper is to highlight current PA strategies that have the potential to increase NUE. Variable rate nitrogen (N) management using crop sensors is one technology that has resulted in improvements in NUE compared with standard, uniform N rates and other site-specific VRN management tools. Combining crop sensors with soil-based management zones (MZ) can further enhance the efficiency of fertiliser inputs. Other research has demonstrated that mounting crop sensors on an unmanned aerial vehicle (UAV) can provide a viable alternative to ground-based sensors while eliminating some of the obstacles to grower adoption of sensor technology. Implementing PA technologies within the context of 4R nutrient stewardship is an efficient and effective way to achieve the goals of sustainable agricultural systems.

Introduction

Goals of sustainable agriculture

In its simplest form, the goal of sustainable agriculture is the production of food, feed, fibre and fuel, without compromising the ability of the future generations to do the same. Thoughts on exactly how this goal should be accomplished are numerous, but one generally agreed upon fact is that concept of sustainable agriculture is multi-dimensional. The concept of sustainability does not apply to economic, environmental, or social drivers as independent of one another, but to all simultaneously. These three sustainability components represent various forms of capital including natural, social, human, physical, and financial (UNCTAD-UNEP, 2008) that will demonstrate resiliency and growth in a sustainable agricultural system. One of the biggest future challenges for sustainable agriculture will be meeting the global food demands that are expected to increase by 100 to 110% by 2050 (Tilman et al., 2011). A key contributor to this necessary increase will be the appropriate use of mineral fertiliser. It is difficult to determine exactly how much crop yield is due to the use of mineral fertiliser because of various factors including inherent soil fertility, climatic conditions, crop rotations, tillage, etc. However, Stewart et al. (2005) reviewed 362 seasons of crop production results and reported at least 30 to 50% of crop yield can be attributed to mineral fertiliser inputs. However, when used at the wrong time, in the wrong, place, in the wrong form, or at the wrong rate, mineral fertiliser can have negative impacts on sustainability. An essential tool in developing nutrient management strategies that will meet the food demands of a growing population, while considering the economic, environmental, and social dimensions of sustainable agriculture, is 4R nutrient stewardship.

4R nutrient stewardship and precision agriculture

4R nutrient stewardship is an innovative approach that provides a global framework for sustainable fertiliser management (IPNI, 2012). At the core of the framework is a simple concept – apply the "right" nutrient source at the "right" rate, at the "right" time, and in the "right" place. Hence, the four "rights' or 4Rs. The novelty of this approach is not in the 4Rs themselves, but in the recognition of the interconnectedness of all four components and the necessity to consider all four simultaneously when determining fertiliser best management practices. What is also unique about the approach is that what is determined to be the "right" combination of practices is site-specific, knowledge-intensive, and relevant to the context of the cropping system. The site-specificity of the 4Rs leads to the common question "How does precision agriculture

‘fit in’ to the 4Rs?” The answer is that it’s not a matter of one concept fitting into another, but rather a realization that they are one in the same – 4R is precision agriculture. While the fundamental principle of 4R stewardship is applying the right source at the right rate, at the right time, and in the right place, precision agriculture is focused on “getting it right” by incorporating as much local information as possible in the management decision-making process and employing the appropriate tools, technologies and information management systems in the farming operation to get it done. The end result for both the 4Rs and precision agriculture is whole farm management of a sustainable agricultural system. The practices selected are also directly tied to sustainability goals for the operation, which are aligned with general goals for sustainable development for the region as identified by local stakeholders. Evaluation of the performance of practices with regard to the economic, environmental, and social priorities of the operation is done using indicators selected in agreement between the producer and the stakeholders. One performance indicator that is garnering increasing attention in current discussions on sustainable agriculture is nutrient use efficiency (NUE).

Nutrient use efficiency

Nutrient use efficiency is a key metric of sustainable crop nutrition as it reflects responsible management as well as relates to the risk of nutrient loss to the environment. However, NUE only addresses some aspects of the overall cropping system and must always be considered in the proper context. For example, management practices that increase NUE but result in lower productivity would not be considered sustainable. Conversely, a low NUE would not necessarily be indicative of an unsustainable practice as applied nutrients can remain in the soil without posing a threat to the environment. Sustainable nutrient management practices must be both efficient and effective. Despite the complexity of the term, NUE is an important concept for evaluating nutrient management practices and improving NUE has been listed among todays most critical and daunting research issues (Thompson, 2012).

The objective of this paper is to highlight precision agriculture technologies that when used within the context of 4R nutrient stewardship have the potential to result in improvements in NUE. Specifically (1) variable-rate N (VRN) application using crop sensors; (2) integrating crop sensing and soil properties for VRN management; and (3) using an unmanned aerial vehicle (UAV) as a crop sensor platform for VRN management.

Variable-rate N applications using crop sensors

Crop canopy sensing has been widely researched and is becoming an accepted practice for determining in-season crop N needs in several countries around the world. There are several commercially available crop sensors including GreenSeeker (Trimble Navigation, Sunnyvale, CA, USA), Crop Circle (Holland Scientific, Lincoln, NE, USA), and CropSpec (Topcon Precision Agriculture, Livermore, CA, USA). All of these sensors are active, meaning they have their own light source, which eliminates the problems associated with ambient light such as cloud cover, low light intensity, shadows, etc. The basic function of all forms of these sensors is to emit light in the visible and near-infrared spectrum and measure reflected light from the crop. Sudduth et al. (2015) evaluated the aforementioned sensors for their ability to discriminate reflectance differences related to maize N health and found that while the operational characteristics of the sensors varied, data from the nadir-looking sensors (GreenSeeker and Crop Circle) were highly correlated with each other and well correlated with maize biophysical data. The CropSpec is an oblique-looking sensor and reflectance measurements were less strongly related to those collected using the other sensors.

Most of the research to date has been focused on developing algorithms that will transform sensor output data, typically in the form of a normalized difference vegetation index (NDVI), into N-rate decisions for the growing crop. Nitrogen rate algorithm development work has been done in a variety of crops including wheat (Raun, et al., 2002), maize (Solari et al., 2008), cotton (Oliveira et al., 2013), rice (Harrell et al., 2011), and sugarcane (Lofton et al., 2012). Most all of the published algorithms have been sensor-specific and incorporate a variety of site-specific information depending on the sensor system being used. The reliance on these complex algorithms has resulted in slow commercial adoption rates despite well-documented success in both small- and large-scale research and demonstration studies.

Thomason et al. (2011) conducted some of the earliest farm-scale, sensor research. They established 15 replicated studies in commercial fields throughout the Coastal Plain region of Virginia, USA. Individual plots were 18.2 m wide and 100 to 122 m in length. Treatments were arranged in a randomized complete block design with six replications and included a standard treatment where the applied N rate was based on tissue N concentration, a variable-rate N treatment applied using a GreenSeeker RT 200 system, which was based on the Virginia wheat algorithm (VWA) they developed in their small plot research (Thomason et al., 2011), and a fixed-rate N treatment that was equal to the average of the VWA recommended rates. Nitrogen source was urea ammonium nitrate (30-0-0) and applications were made using a Spra-coupe 220 self-propelled sprayer (AGCO, Duluth, GA, USA) equipped with a 18.2-m boom, a Raven 440 flow rate controller (Raven Industries, Sioux Falls, SD, USA), and TeeJet 11008 or 11006 nozzles (TeeJet technologies, Glendale Heights, IL, USA). Their results showed that the standard GS30 N rate (determined based on tissue N content) and the rate determined using the VWA resulted in yields that were similar at 13 of the 15 sites (Figure 1). The VRA resulted in higher yield at one site and lower yield at another. However, recommended N rates were lower using the VWA at 9 sites by an average of 12 kg/ha, representing a decrease in average N recommendation of approximately 7% (Figure 1), which would result in a higher NUE. The fixed-rate treatment equal to the VWA average recommended rate resulted in lower yields compared to those found in the VWA or standard rates; thus, emphasizing the need to treat the spatial variability of N need in order to achieve comparable yields with N rate reductions (data not shown).

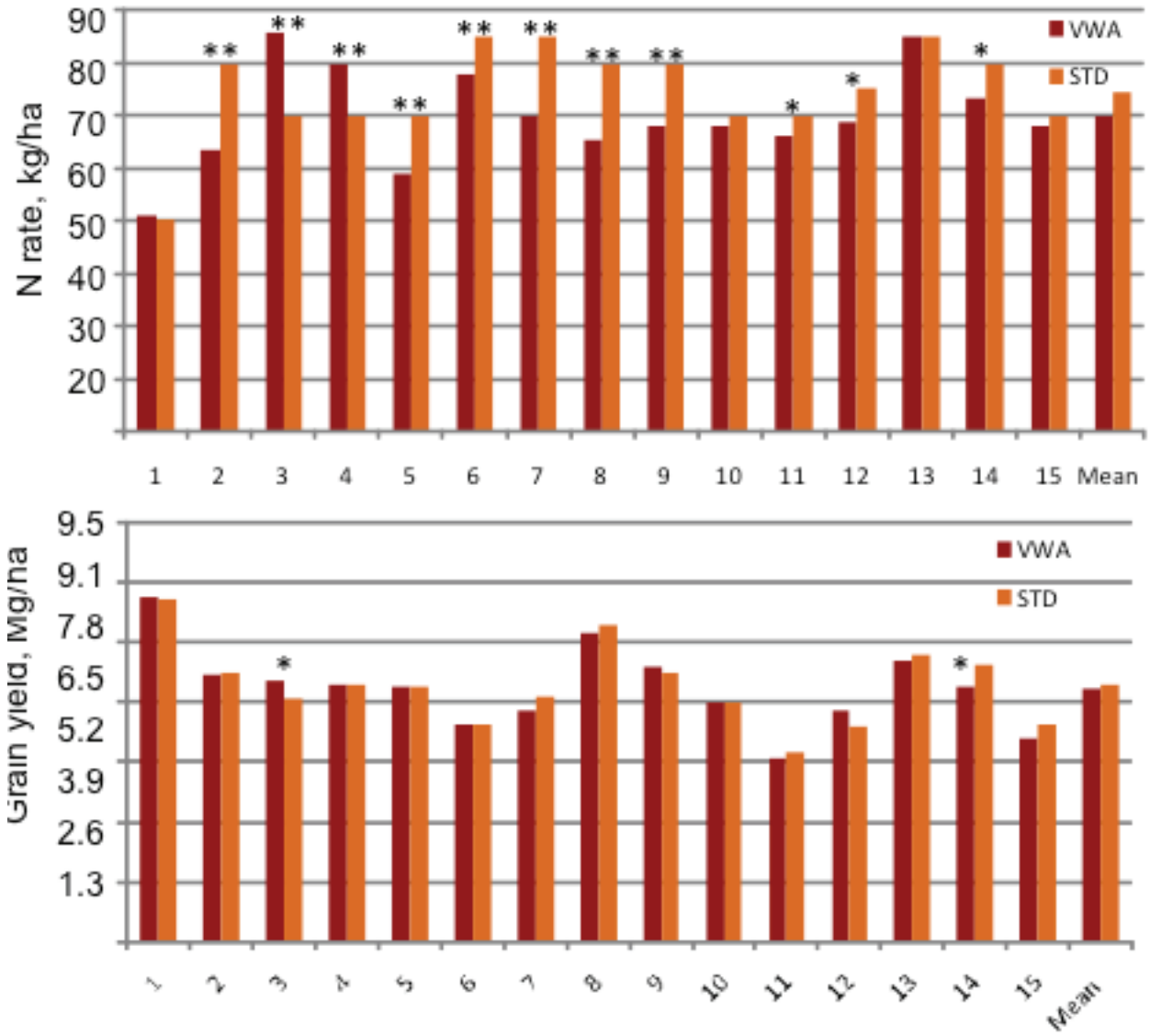


Figure 1. Mean grain yields and topdress N rates determined using the Virginia wheat algorithm (VWA) applied via GreenSeeker versus the standard (STD) method of using tissue N concentration at growth stage (GS) 30 for 15 sites in Virginia.

In more recent work, Chim et al. (2014) compared the GreenSeeker with other site-specific N rate decision support systems. In addition to GreenSeeker, they evaluated the Maize-N computer simulation program (Yang, 2015) and the Nutrient Expert software (IPNI, 2015) compared with the standard yield goal-based N recommendation for maize in VA. They found that all of the site-specific methods resulted in higher grain yield than the yield goal-based method, but NUE varied among methods (Figure 2).

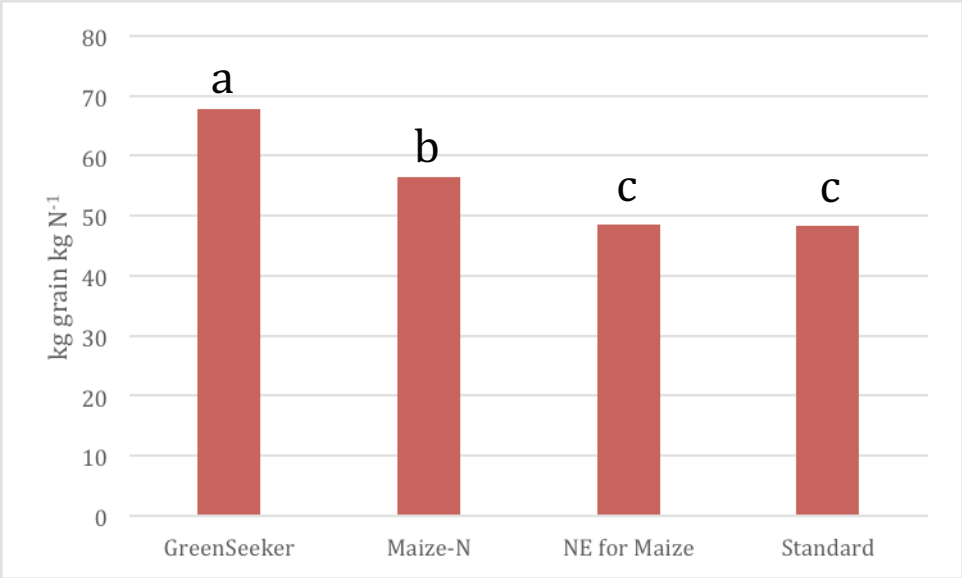
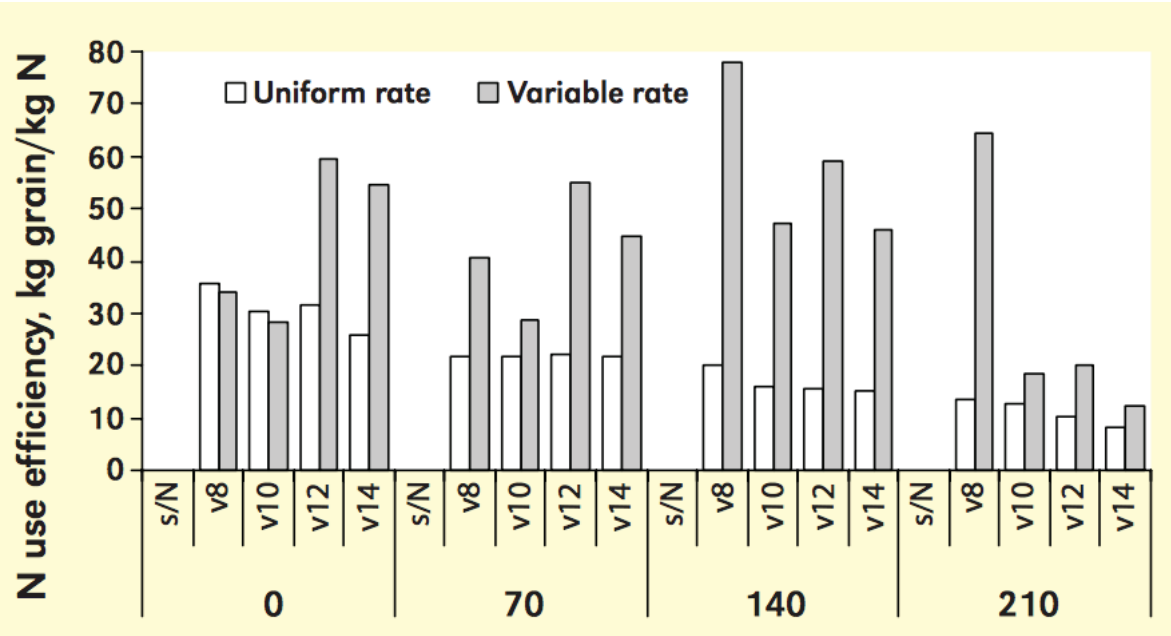


Figure 2. Nitrogen use efficiency, calculated as kg grain per kg N fertiliser applied via various decision support systems averaged over seven locations in Virginia, USA.

Melchiori (2010) also reported increased NUE in maize using GreenSeeker-based N rates compared with a standard fixed rate. Their work covered seven growing seasons in Argentina and evaluated the ability of the GreenSeeker to determine optimum sidedress N rates for maize across a range of growth stages and pre-plant N rates. Similar to other published studies, they found no difference in grain yield between the methods, but a higher NUE when using the sensor-based system (Figure 3).

Figure 3. Nitrogen use efficiency in maize following N fertilization between V8 and V14 using sensor-based variable rates or uniform fixed rates at varying levels of pre-plant N fertilization.



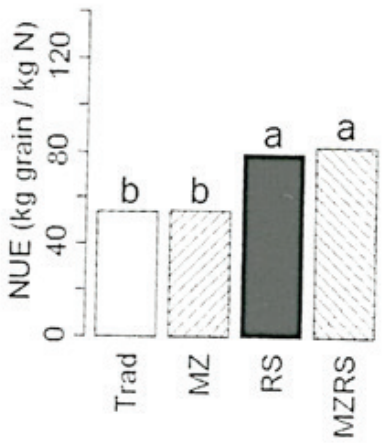
The commercial use of crop sensors has begun to increase more rapidly in the past few years, particularly in the U.S. and Europe. In late 2012, the US-based website, precisionag.com, released its annual ranking of the top trends in precision agriculture. Crop canopy sensors were identified as the "up and coming" technology to watch for. This was an interesting prediction because at the time, only 4% of precision ag service providers were offering sensor-based N fertilization (Holland et al., 2013). However by the end of 2013, crop sensing service offerings had nearly doubled among Midwestern US service providers (Erickson and Widmar, 2015); however this still only represented 7% of dealerships, while 70% of those same dealerships offer VR fertiliser application based on soil maps. Reasons for the slow adoption since sensors first became commercially available a decade ago have to do with various factors. One that was mentioned earlier is the complexity and "black box" aura of the N rate algorithms. Growers don't want to be overwhelmed with highly sophisticated decision support systems, but they do need some assurance that there is value in what they are paying for. Another has been an early lack of technical support from the manufacturers for some of the sensors. This obstacle is being addressed as less than 20% of dealers find a lack of manufacturer support to be a major obstacle for adoption (Erickson and Widmar, 2015). Another improvement that should lead to higher adoption rates is that as precision agriculture becomes more and more data-driven, multiple layers of information, such as various soil properties, can be incorporated into, or used to complement, the existing algorithms, creating a more robust prescription service for growers.

Integrating crop sensing and soil properties for VRN management

The benefit of dividing fields into homogeneous areas and treating the areas as independent management zones (MZ) is well documented (Khosla et al., 2002; Koch et al., 2004). Various layers of site-specific information such as soil fertility, soil organic matter, soil texture, grain yield, soil EC, and others are combined and similar areas with regard to productivity are delineated. Several of these layers are commonly offered both for collection and analyses by precision ag service providers (Erickson and Widmar, 2015). Nearly 70% of dealers in the Midwestern US offer GPS-based grid soil sampling; 60% conduct GPS-based field mapping, and over half offer yield monitor data analysis. Half of the dealers also offer satellite imagery, another popular layer for MZ delineation (Erickson and Widmar, 2015). Managing fields based on zones has been shown to improve grain yield, nutrient uptake and NUE (Khosla et al., 2002; Koch et al., 2004). Management zones are also effective as part of a 4R approach as they help guide the right fertiliser rate to the right place in the field and have been shown to result in increased profitability and reductions in excess nutrient loading that could have the potential to negatively impact the environment. Despite the clear benefit to MZ and the aforementioned value associated with crop sensing, few studies have investigated the potential to incorporate both approaches into a single management strategy.

Longchamps et al. (2015) conducted a three-year study in a 4.5-ha field in Colorado, USA to determine whether VRN management using both MZ and crop sensors would improve NUE over MZ or crop sensors used alone or the traditional single-rate approach. Management zones were delineated for the study according to the procedures described by Hornung et al. (2006). Data layers included: bare soil aerial image, the farmer's perception of the topography data, and farmer knowledge regarding soil management and productivity zones. Zones were then classified as low, medium, and high according to productivity. Sensor data were collected using a GreenSeeker sensor. Data processing and analyses, as well as, N rate assignments to zones and spatial distribution of treatments in the field are reported in Longchamps et al. (2015). Their results demonstrated that NUE was improved with both VRN strategies using the sensor over the traditional or MZ approaches (Figure 4).

Figure 4. Average NUE obtained using different management strategies; Trad - traditional uniform N rate; MZ – VRN based on management zones; RS – VRN based on crop sensing; MZRS – VRN based on combination of management zones and crop sensing.



Using UAVs as a crop sensor platform

While nearly all precision ag services are expected to increase in the next three years, the one poised to make the biggest leap is the use of UAVs (Erickson and Widmar, 2015). Thirty-eight percent of dealers expect to be offering UAV-related services by 2018, up from 19% in 2015. Commercial data collected using UAVs have included harvest and planting videos, crop scouting imagery and NDVI images. The NDVI maps have been used to develop variable rate N application maps so the question can be raised, "Can an active crop sensor be mounted on a UAV for VRN management?" The earliest answers are coming out of a research group at the University of Nebraska, USA. Krienke et al. (2015) conducted a study in the summer of 2014 to compare normalized difference red edge (NDRE) reflectance measured using a ground-based with a UAV-mounted crop sensor. The sensor used was a handheld Crop Circle Rapidscan and the UAV was a MikroKopter OktoKopter XL (MikroKopter, Moormerland, Germany). They compared the two platforms viewing actively growing turfgrass and maize crops. Specific details of the experimental methods are reported in Krienke et al. (2015). Their results showed a strong correlation between measurements collected using the handheld sensor (HA) and the UAV-mounted sensor (Figure 5).

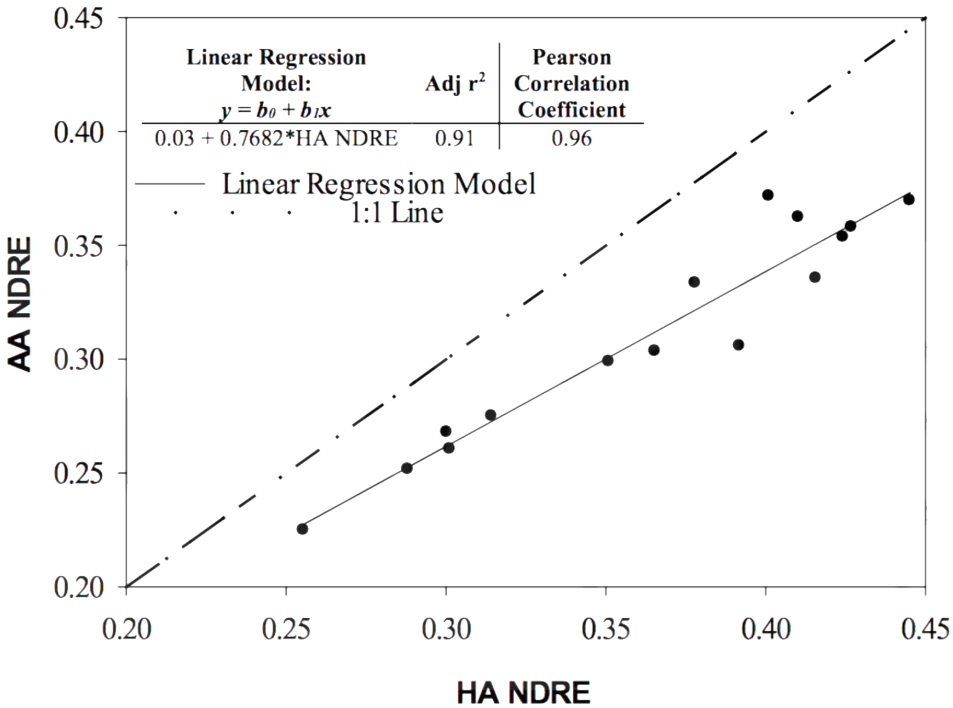


Figure 5. Regression relationship of NDRE reflectance between handheld (HA) and UAV (AA) sensor platforms.

These data suggest that the UAV platform is a viable replacement for ground-based sensors; however, their results also demonstrated a height effect on NDRE measurements. They recommended that UAV-based NDRE measurements be taken between 0.5 and 1.5 m above the crop canopy when being used for making variable rate N recommendations. The ability to mount crop sensors on UAVs should further contribute to the adoption of sensor technology as a VRN management strategy because one of the complaints of growers reluctant to adopt the technology is that the on-the-go nature of the current sensor systems makes them uncomfortable, as they can't preview the N rates prior to application in the field. UAV-mounted sensors will also add value to the system by allowing post-fertilization mapping to estimate crop responsiveness to N.

Conclusions

To meet the food production challenges for a growing population in a sustainable manner, continuous improvement in agricultural system performance will be required. This improvement will depend on a combination of technology, agronomy, management and policy support developments, and changes must occur across several disciplines of agriculture and society. Implementing PA technologies within the context of 4R nutrient stewardship is an efficient and effective way to help meet the environmental, economic and social goals of sustainable agricultural systems.

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Development of a soil sulfur test and sulfur enhanced fertilisers from the soil up

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Abstract
A series of field and glasshouse studies, mostly utilizing ^{35}S, have been undertaken to study S pools and transfer rates in soil. These studies highlighted the role of ester sulfates in supplying S to the solution SO_4^{2-} pool, which supplies S to plants. This knowledge was used to assess the suitability of a range of soil extracts to predict the S supplying capacity of the soil. A test using 0.26 M KCl heated at 40°C for 3 hours was found to be most suitable and this has been adopted in most accredited soil test laboratories in Australia.

Similarly, a series of detailed studies on elemental S oxidation have been undertaken and the knowledge obtained from these have been used to develop a range of elemental S coated and S incorporated fertilisers. By working closely with commercial fertiliser manufactures a range of S enhanced DAP, MAP and TSP fertilisers are now available, which commonly contain 8-12% S with 1/3 sulfate and 2/3 fine particle sized elemental S incorporated in the granule. These fertilisers have been tested extensively in a wide range of environments and crop and pasture systems.

Key words
sulphur, fertilizer,soil test,sulphur oxidation,

Introduction
Up until the 1950s little attention was paid to sulfur (S) as a plant nutrient mainly because it had been applied to soil in incidental inputs in rainfall and volcanic emissions and as a component of nitrogen, phosphorus and potassium fertilisers. Prior to that time experimentation concentrated on superphosphate responses, with the emphasis on phosphorus.

Reports in 1915 and 1926 from the Glen Innis Research Station in New South Wales mention responses to potassium sulfate and gypsum (Blair and Nicholson, 1975). The soils on which these experiments were conducted were subsequently shown to be non-responsive to potassium and calcium hence this may be the first recorded response to S in Australia. The first published experimental evidence was by Anderson and Spencer (1950) on soils from the Southern Tablelands of New South Wales.

Plant metabolism depends on S and a deficiency of this nutrient will cause basic metabolic impairment, which will not only reduce crop and pasture yield but also the quality of produce (Duke and Reisenauer, 1986). Deficiency symptoms of S in plants includes a yellowing of the younger leaves as a result of a low chlorophyll production and S non-mobility (Yoshida and Chaudhry, 1979) and a marked reduction in plant height and tiller number in cereals (Blair et al. 1979).

The awareness of S deficiency is increasing and areas of S deficiency are being recognised in previously S sufficient areas of the World.

There are many reasons of increasing S deficiency but the most important I have listed in Blair et al. (1978) as follows:

i) the increasing use of high analysis, low S containing fertilisers;
ii) the increase in yields obtained as a result of other technological advances;
iii) the decreasing use of S containing pesticides and fungicides;
iv) environmental control of sulfur dioxide emissions in industrial areas and fuels; and,
a greater number of experiments conducted where S is studied as a nutrient in its own right.

The S cycle

The S cycling literature has been extensively reviewed; for example Till (1975) and Blair (1986). The S cycle has similarities to both N and P cycles. The role of organic sources in supplying sulfate to plants is similar to both the N and P cycles and the adsorption reactions are similar to P reactions although the strength of sulfate adsorption is considerably less than for phosphate.

A diagram of the S cycle is shown in Figure 1. Uptake by plants is from the "available SO_4^{2-}" pool, which also supplies SO_4^{2-} to, and receives SO_4^{2-} from, some of the other components in the soil-plant-animal cycle at a range of rates. In addition, there are various other environmental input and loss processes which can make significant differences to the S balance of the whole system.

The plant will continue taking up SO_4^{2-} from the available pool and, in its simplest case the fertiliser can be considered as another source of SO_4^{2-} that becomes available at some rate and the plants compete with the other processes for it. Under normal circumstances as soon as the fertiliser S enters the system it becomes indistinguishable from that already in the cycle.

Work on S cycling related to pasture improvement in temperate conditions has been conducted by Till and May (1970) using radiotracers. In these studies, ^{35}S applied in fertiliser could still be detected two years after the initial application, indicating a long residual effectiveness. This radiotracer work emphasized the role of organic matter as the major temporary storage pool for added fertiliser in the system and provided a basis for a simple model and simulation studies, which showed the importance of process rates within the cycle (May et al. 1973).

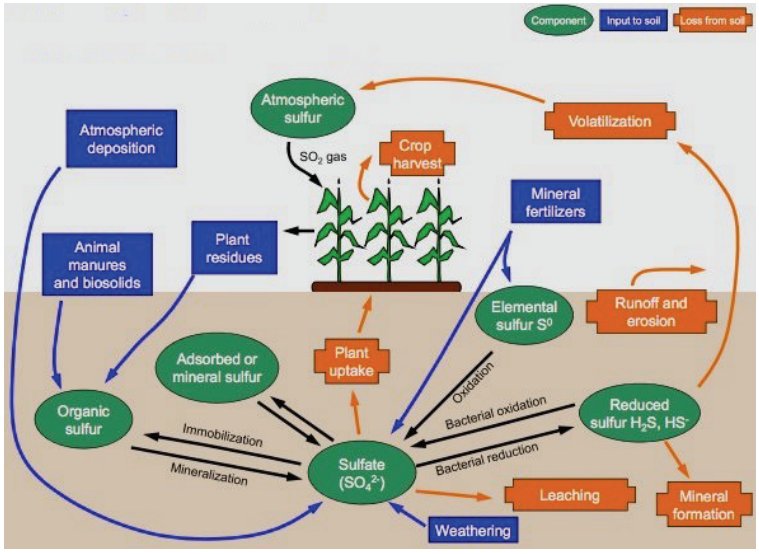

Figure 1. S pools and pathways in Agricultural systems
Source: https://upload.wikimedia.org/wikipedia/en/7/71/SulfurCycle_copy.jpg

Sulfur Soil testing

Soil testing to determine the S status of agricultural systems has met with variable success. The poor ability of the widely used mono-calcium phosphate extractant to identify S responsive soils is highlighted by the data from India in Figure 2.

A number of reasons for this have been outlined in reviews by Freney (1986). The nature of the S cycle in soil, which includes four main pools, contributes to this poor performance.

These pools contain:

- sulfate in the soil solution which is the source of S for plants and which can move in the soil water and/or be adsorbed.
- adsorbed sulfate, which is bonded weakly to positively charged colloid surfaces. In highly weathered soils not all of this S may be accessible to plant roots
- ester sulfates, which are a group of compounds containing a C-O-S linkage. The content of these •

compounds in the soil can be determined by digestion with hydriodic acid (HI). They are important because the C-O-S bond can be split on drying to release plant available SO_4^{2-}.

- carbon bonded S has a strong C-S bond which is difficult to break. This pool of S provides the long term supply to plants and is therefore less important to soil test results.

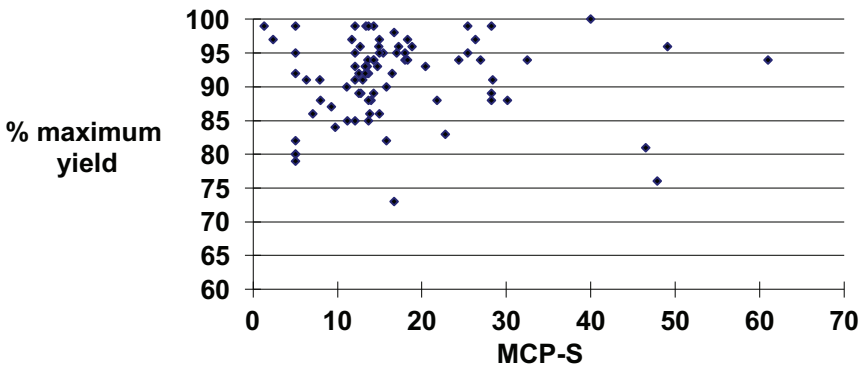

Figure 2. Relationship between mono-calcium phosphate (MCP) extractable S and % maximum yield in field trials in India conducted by The Sulfur Institute.

Plants take up their sulfate from the soil solution pool, which receives S from both the adsorbed and organic S pools. The organic S pool contains two major sub-pools, namely ester sulfates and carbon bonded S. Soil extractants used to determine the S status have most commonly involved a measurement of the sulfate in the soil solution plus adsorbed S. Amongst the extractants used, calcium dihydrogen orthophosphate containing 500 mg P/mL has been the most common.

Blair (1979) tabulated data from the world literature on critical levels of soil S. In doing this he partitioned the extractants into those which extract readily soluble sulfate, readily soluble plus portions of adsorbed sulfate, readily soluble, adsorbed and a proportion of organic sulfate. Within each of these groups, variable critical levels have been proposed. Generally, correlations between extractable S, using these types of extractants, and plant response have been poor. As for other nutrients local calibration of a soil test is critical if sensible predictions are to be made of S status.

Simulation modelling of agricultural systems (McCaskill and Blair 1988) indicates that fluxes of S from the organic pool play a major role in supplying S to agricultural plants, particularly in pasture systems where organic matter levels are high.

The importance of the ester sulfate pool is highlighted by the data of Blair et al. (1994) (Figure 3). In this experiment, where ^{35}S was used, the ryegrass plants acquired SO_4^{2-} from the MCP-S extractable pool and the HI-S (ester sulfate) pool and at 98 days in phase 1. When the plants and sulfate S were removed from the soil and new plants established in phase 2 the HI-S (ester sulfate) pool provided S to the plant and to the MCP-S pool.

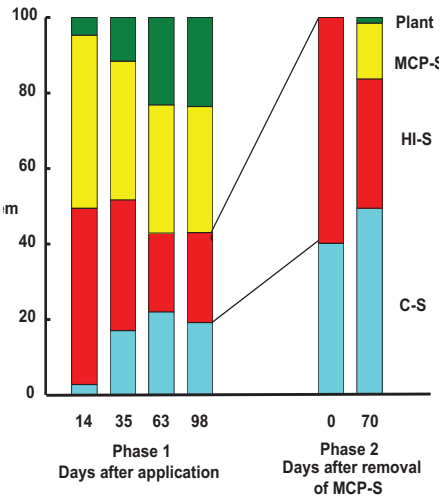

Figure 3. The pools of soil S accessed by ryegrass in a pot experiment showing the importance of HI-S (ester sulfates) in supplying sulfate to the plant available pool. Blair et al. (1994).

In the pot experiment of Blair et al. (1994) the loss of S from the MCP-S and gains to the plant, HI-S and C-S pools in the first 63 days (Table 1) shows how rapidly S fluxes occur in soils after the addition of 35SO42-
. The incorporation rate of 35SO4 into the HI-S and C-S pools was considerably higher than that found in New Zealand by Goh and Gregg (1982), who found that from 17 to 40% of added sulfate was present in organic forms within 34 to 75 days. The finding that only the HI-S pool had a negative transfer rate (loss of S from pool) in the 0-70 day period of phase 2 (Table 1) supports the finding of Freney et al. (1971). They found that most of the available S removed by plants over a 9-month period came from the ester sulfate fraction although there were changes in all soil fractions.

Table 1. Net transfer rate of ^{35}S in plant and soil pools in Phase 1 and Phase 2 of the experiment of Blair et al. (1994).

S Pool	Net transfer rate (%/day)	
	0-63 days	0-70 days
Plant	+0.36	+0.07
MCP-S	-1.05	+0.20
HI-S	+0.33	-0.38
C-S	+0.35	+0.02

An evaluation of a range of soil S tests has been undertaken by researchers at the University of New England, Australia. Blair et al (1991) compared H_20, 0.01M $Ca(H_2PO_4)_2$ (MCP), $NaHCO_3$ and KCl-40 in a series of field and glasshouse studies. In the KCl-40 procedure the soil is extracted with 0.25 M KCl at a temperature of 40 °C for 3 hours and the inorganic and organic S in the extract measured. The various soil S pools being utilised by plants has been evaluated by Chaitep et al. (1994) in an experiment with flooded and non-flooded rice grown in a glasshouse. In this evaluation plants were grown in soil which had been incubated for 3 weeks with ^{35}S. This allowed equilibration of the radioactive tracer with the various soil pools. Flooded and non-flooded rice was then grown to maturity in the glasshouse and the ^{35}S and total S in the above-ground biomass determined. The ratio of ^{35}S/ total S is termed the specific radioactivity and this ratio in the plant is compared with the specific radioactivity in the soil extract (termed the specific radioactivity ratio, SRR). When this ratio equals 1 it indicates that the plant is removing S from the same or similar soil S pools as the extractant. The data in Table 2 shows that the SRR value is closest to 1 for the KCl-40 extract among the extractants evaluated indicating that this extractant was removing S from similar pools as the plant.

Table 2. Specific Radioactivity Ratio (SRR) between plants and extracted S for a range of chemical extractants.

Extractant	System	
	Non-flooded	Flooded
H_2O	0.88	0.85
MCP	0.83	0.79
KCl-40	0.92	0.92
$NaHCO_3$	0.27	0.19

Research by Chinoim et al.(1997) has shown that the KCl-40 extract generally removes more S from the ester sulfate pool (shown as loss from HI-S in Figure 4) than MCP. In the data from a granite soil shown in Figure 4 the amount of S extracted from the sulfate and organic S pools was also greater than with MCP, but this is not always so. Because MCP removes more S from the adsorbed sulfate pool than KCl-40 the MCP value is always higher than KCl-40 in soils high in S and with a high S adsorption capacity.

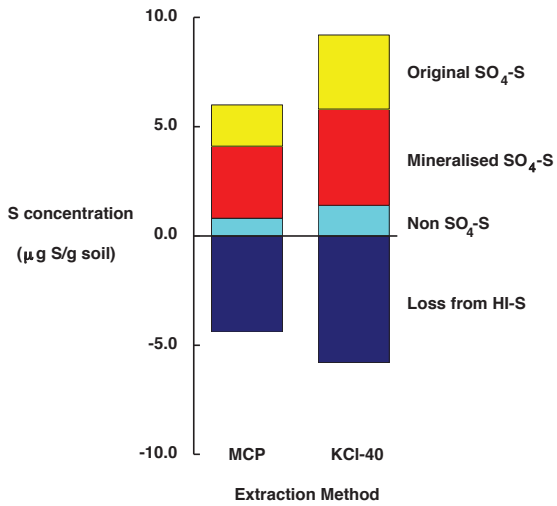

Figure 4. Sources of S removed by KCl-40 and MCP from a granite soil and S transformations that take place during extraction (Chinoim et al. 1997).

In the development of the KCl-40 method Blair et al. (1991) found a coefficient of determination (r^2) of 0.74 between extractable S and percent of maximum yield on a range of 18 pasture soils collected from Northern New South Wales, Australia (Table 3). In a supplementary study, where radioactive S had been added to rice soils, it was found that the KCl extract removes a portion of the HI reducible ester sulfates, which are believed to be rapidly turning over in soil systems. It is hypothesised that the greater accuracy of this test results from the extraction of soil sulfate, adsorbed S and a portion of the actively turning over organic S components in the soil.

Table 3. Coefficient of determination (r^2) between extractable S and percent of maximum yield for a range of extractants on a range of 18 pasture soils collected from Northern New South Wales, Australia.

Extractant	r^2
H_2O	0.47
MCP	0.48
KCl-40	0.74
$NaHCO_3$	0.15
Total S	0.03

A schematic of the various pools accessed by plants, and removed by a range of extractants, is shown in Figure 5.
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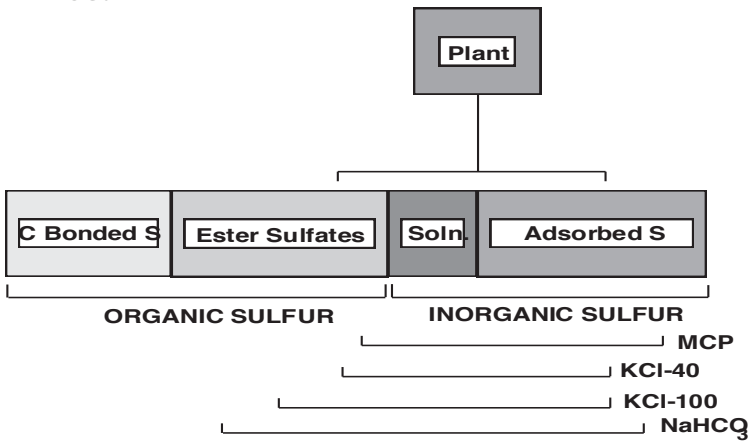

Figure 5. Schematic of the S pools accessed by plants and removed by a range of extractants.

The ability of S soil tests to indicate responsive and non-responsive sites was examined by evaluating the number of times the soil test, measured at the start of the experimental year, was above the critical level (6.5 µg/g for KCl-40 , Blair et al. 1991), and 10 µg/g for MCP (Incitec) and the response to S in that year

was statistically non-significant (i.e. a correct prediction of a non-responsive site) or statistically significant (i.e. a correct prediction of a responsive site). In the first instance the soil test prediction was correct more often with the KCl-40 extract than with MCP. The KCl-40 extract was also more often correct in predicting responsive sites in 2 out of 3 years for which data was available.

Several sites were notable in the poor performance of the soil tests and these were those where extractable S was present below the sampling depth (e.g. Site Q1, Malanda, S23, Nangwarry Figure 6). Probert and Jones (1977) observed a similar situation in their North Queensland studies and used a weighted profile mean to overcome the problem.

The KCl-40 procedure has now been adopted by most accredited soil test laboratories in Australia.

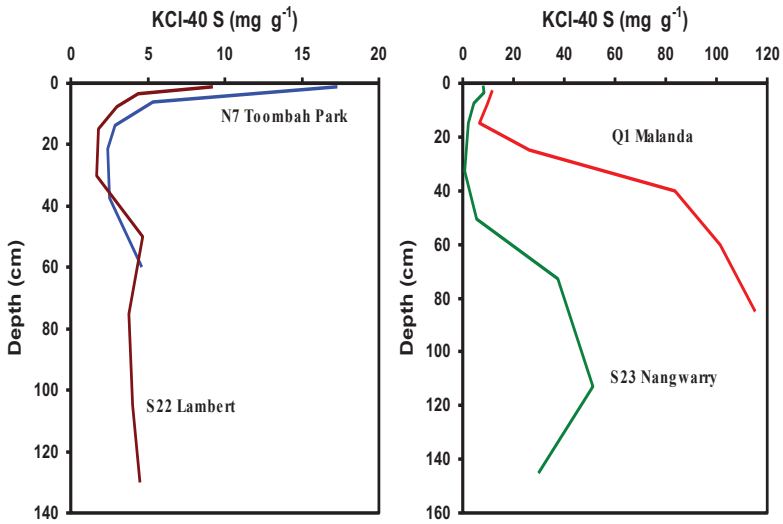

Figure 6. KCl-40 extractable S in profiles of four soils from Australia.

Development of new S containing fertilisers

Intensification of cropping systems using high-yielding varieties has accelerated S removal from the soil, which has resulted in more soils becoming S-deficient. Increased use of high-analysis S-free fertilisers such as MAP, DAP, TSP and urea has aggravated the S deficiency problem.

Many alternative sources of S fertiliser are available (Blair 2002). Fertiliser sulfate is immediately available to the crop (Friesen and Chien, 1986), but leaching losses may be significant from these fertilisers. Elemental S must undergo oxidation to plant available sulfate and both moisture and aeration are interrelated factors that affect the rate of oxidation of elemental S. Generally, elemental S is oxidised most rapidly at a moisture content of approximately field capacity (Moser and Olsen, 1953), which is the optimum soil moisture for plant growth (Burns, 1968), so the SO_4 is largely released in synchrony with plant demand.

Equations for incorporating the effects of soil temperature and moisture on S oxidation and plant S demand were developed from published data (McCaskill and Blair 1989) and these were incorporated into a simple model to predict sulfate supply from single superphosphate and elemental S. The model predicted that after 72 days 99% of the S in single superphosphate would have been released from the fertiliser granule. By contrast the release and oxidation of S from elemental S fortified single superphosphate (36% elemental S, 9% sulfate-S) was 54% after 1 year and only 23% from crushed agricultural grade elemental S..

Elemental S is an almost ideal fertiliser as it contains 100% nutrients, hence its inclusion into fertilisers such as DAP, MAP and TSP does not dilute the content of other nutrients in the fertiliser nearly as much as does the inclusion of sulfate.

Many studies have demonstrated that the rate of oxidation is proportional to the surface area of S exposed and hence inversely proportional to the particle size (Fox et al., 1964). Shedley et al. (1979) showed that S oxidation was complete from 50 µm particles 70 days after the commencement of his experiment and he also found that in the coarser particle size treatments the release of sulfate continued throughout the 1 year experimental period.

Sholeh et al. (1997) found marked differences in S oxidation between 50-150 and 150-250 μm particles in the presence of P but little difference when P was absent (Figure 7). This has important implications for incorporation of elemental S into fertilisers and indicates that P containing ones are the best candidates.

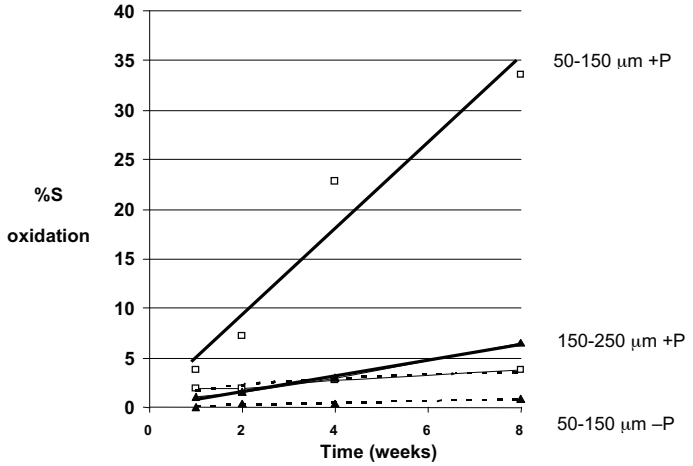

Figure 7. Effect of elemental S particle size and the presence of P on the % of elemental S oxidised over an 8 week period (Sholeh et al. 1997).

In studies undertaken at UNE (Kubelo, 2008) S oxidation rates were higher at 30°C than at 18°C over a range of particle sizes with the difference becoming less as particle size increased (Figure 8).

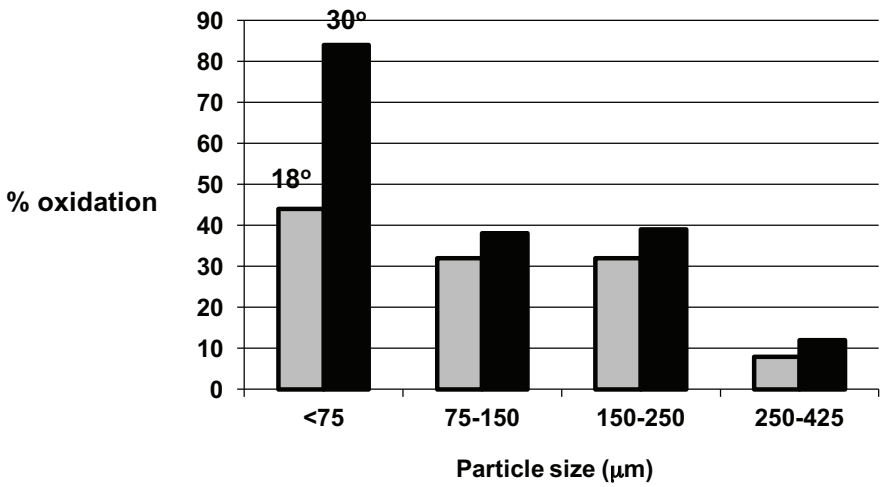

Figure 8. Effect of temperature and particle diameter on S oxidation at 6 weeks.

Elemental S containing P based fertilisers were introduced to the Eastern Australia market in 1957 in the form of S fortified SSP. This was made by spraying molten elemental S into the den during manufacture.

Freisen et al. (1987) compared the P and S release from partially acidulated rock phosphates and found that the presence of elemental S increased both P and S release from the fertiliser. Australian fertiliser manufactures did not take up this technology as they had considerable investments in single superphosphate plants, which needed to be run at full capacity to be economical.

This basic research conducted by the University of New England (UNE) team has been used to develop a range of S coated fertilisers and in 1991 a patent was granted to UNE for a S coating process (Blair, 1991). Work continued for the next 15 years to refine the process and to develop a range of coated DAP, MAP, TSP and urea coated products (Blair et al. 1994, Dana et al. 1994, Yasmin et al. 2007). During this period Hi-Fert began marketing S coated products under the Goldphos name.

Shell invented a process in 2001 to include microfine elemental S into DAP and MAP and a patent for this was filed in 2003 (International Publication Number WO 2004/043878 A1). The design of the products to be produced was based on the UNE research and I was invited to become a Special Advisor on Agronomy and

Soils to the "Thiogro Project". Much of the process developmental work on Shell Thiogro was undertaken at the International Fertilizer Development Centre (IFDC) in Muscle Shoals, Alabama, USA where a reactive granulation process was developed using pre-neutralizers (PN), pipe cross reactors (PCR) and combination of PN and PCR units with S concentrations ranging up to 20% by weight.

In the Shell Thiogro S enhanced MAP and DAP processes, molten S is added to the ammonium phosphate slurries, along with small concentrations of proprietary additives to emulsify the hydrophobic elemental S into a hydrophilic ammonium phosphate slurry/melt. This results in phosphatic slurry containing discrete elemental S particles with an average size ranging from 20 to 60 microns. The reactor slurry is subsequently granulated in conventional rotary drum granulator. Commercial fertilizers made using this process commonly contain 10-12% S. Because of the risk of a delay in oxidation following application, 1/3 of the S is added as sulfate and 2/3 as elemental S.

A distinguishing feature of the Shell Thiogro process is that the elemental S is uniformly distributed throughout the fertiliser granule, which reduces the risk of potentially explosive S dust being generated as the fertiliser particles abrade during handing and ensures that the elemental S and P are in close proximity to promote S oxidation.

S oxidation from fine elemental S (Sº) and from S incorporated into Shell Thiogro MAP has been studied extensively at UNE and results from one such study are presented in Table 4. The trial was conducted in a temperature controlled glasshouse set to simulate subtropical conditions with day and night conditions fluctuating around 25 ºC**.** The results showed that there was no significant difference in S recovery by the maize plants between fine elemental S (<48.1µm) mixed throughout the soil or from the 1/3 sulfate/ 2/3 elemental S contained within the Shell Thiogro MAP (12%S) when both were applied at the equivalent rate of 10 kg S/ha.

Table 4. Dry matter yield and S uptake by maize after 44 days.
Numbers within a column followed by the same letter are not significantly different (p<0.05).

Treatment	Dry Weight (g)	Total S uptake (mg/pot)	Recovered S (%)
Fine (<48.1µm) Sº	4.72a	7.03a	25.6a
Shell Thiogro MAP12	4.50a	6.11ab	20.5a

A total of 138 replicated randomised block plot experiments have been conducted to evaluate Shell Thiogro. Experiments have been conducted in China (101 experiments), Brazil (22 experiments), Argentina (10 experiments) and Australia (7 experiments). Two experiments in Australia did not produce results due to drought or hail damage meaning that results are available from 136 experiments in total.

Of the 136 experiments 84 were responsive (difference between minus S control and Shell Thiogro treatment significant at p=0.05 according to Duncan's Multiple Range Test) to S with a weighted mean yield increase to Shell Thiogro of 14%, compared with the zero S control. The comparison treatment consisted of a mixture of MAP and gypsum used to simulate an addition of single superphosphate (SSP). Nitrogen and all other nutrients were balanced between treatments so that S was the only variable. Shell Thiogro produced yield responses equal to SSP at 50 sites, responses exceeding SSP at 28 sites and responses inferior to SSP at 6 sites.

An S enhanced triple superphosphate TSPS fertiliser has been developed by Yunnan Lufeng Qinpan Phosphor Chemical Co., Ltd., China, which is based on the UNE research and it contains 8.5% S present as 1/3 sulfate and 2/3 elemental S within the fertiliser granule and this is now on sale in the New England Tablelands of NSW.

Conclusion

The sound basic research, which has had good long term financial backing from Australian Research Corporations, AusAid, ACIAR and Commercial interests and an enthusiastic group of post-graduate students

and Research Fellows has led to the development of a robust S soil test and to a new generation of S containing fertilisers. Persistence pays!

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From adversity comes strength – repositioning education in agriculture

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Abstract
Much has been written about the decline in agriculture graduate numbers over recent times and the shortages created in the market place. At the same time, there has been an increased urgency towards professionalising the industry – a focus on education and training, a desire to improve the image of the sector, a move towards social licence and greater engagement with future opportunities, challenges and needs. This paper takes a fresh approach to these issues; drawing together the less commonly reported data on student enrolments in agriculture, the distortions created by misunderstanding course classification data and the emerging focus on learning and teaching academic standards in tertiary education. Decline in enrolments from 2001 has resulted in massive loss of income to university departments with commensurate contraction of academic staff numbers and expertise. The decline has now been addressed although it remains work in progress. The development of a national Learning and Teaching Academic Standards Statement (LTAS) for university Agriculture (AgLTAS) represents a significant positive step that engaged academic, student and industry stakeholders in its development. We expect that the AgLTAS statement will facilitate the implementation of academic standards by the agriculture discipline community, inform curriculum design, assist in identifying marketing opportunities for degrees and contribute to the further professionalization of agriculture.

Key words
Higher education, learning and teaching academic standards, enrolment, field of education

Higher education in agriculture and related disciplines
Agriculture and related disciplines are offered in 14 Australian universities as a three- or four year specialist degree or as a major in a science degree.

In 2007, the then Australian Institute of Agricultural Science and Technology held a colloquium to consider the paucity of agricultural graduates entering the workforce. Universities received considerable blame from industry for the lack of graduate output but it was unclear what steps industry itself had taken to promote careers in the sector. One outcome of that meeting was the formation of the Australian Council of Deans of Agriculture (ACDA) in 2007. The Council is made up of those Universities in Australia that undertake education and research in agriculture or related agricultural areas. It represents issues of common interest as they affect agricultural activities in universities and cooperates on projects of mutual benefit. It links and works with relevant government agencies and industry organisations to improve the performance and sustainability of Australian agriculture and to raise the overall education level of the sector.

A first step by the ACDA was to approach the then Federal Minister for Primary Industries to inform him that the number of professionals in agriculture with tertiary qualifications was in decline. He responded that the official position of government was that there were 'plenty of agriculture graduates and insufficient jobs', a position diametrically opposed to the view being expressed by ACDA. The Deans resolved to collect their own statistics, which have since been published at various times (Pratley 2008; Pratley *et al.* 2008; Pratley 2012). These statistics were a collation of the graduate data of Universities.

At the same time, in conjunction with the agricultural graduate employment company Rimfire Resources Ltd, analysis of the job advertisements in newspapers and the internet was undertaken to gain a better understanding of the employment market. The McColl Report (1991) into agricultural and related disciplines demonstrated that there were insufficient graduates, despite a buoyant employment market, to meet the needs of the agricultural industries. Despite this finding, the numbers of students graduating from the higher education institutions in Australia continued to decline until at least 2012 (Figure 1). The data showed

that there were up to six jobs for every graduate each year for the previous seven years. Although this has softened in 2014 (Figure 2), the market suggests that there are still about four jobs for every graduate. These data do not account for direct targeting of prospective employees by the agricultural industries. The latter seems to be significant. The revelations brought forward by ACDA created a substantial response from politics in the form of reviews, from industry and from educators (Cowan 2010; Australian Government 2012; Parliament of Victoria 2012; Pratley 2013). The reviews highlighted the lack of a positive image for agriculture, the perception that agriculture related only to farming, the negativity towards agriculture in the schools and the complacency in the education system and the community about food security. Students were actively discouraged from choosing agriculture as a career by school career advisors who perceived there were no jobs (Pratley 2013).

There were diverse responses and outcomes from these reviews:

- The agricultural industries realised that the lack of graduates was real, generating concern about its capacity going forward and the impact on future opportunities. Issues such as social licence became important;
- A resurgence in interest in agriculture in the broader community came from highlighting the link between the sector and global food security and sustainability;
- The importance of educating children about food and agriculture was elevated. This highlighted the activities of organisations allied with the ACDA, such as the Primary Industries Education Foundation Australia (PIEFA);
- The collective view of the ACDA that the impact of lower enrolments on universities was of national concern was reinforced.

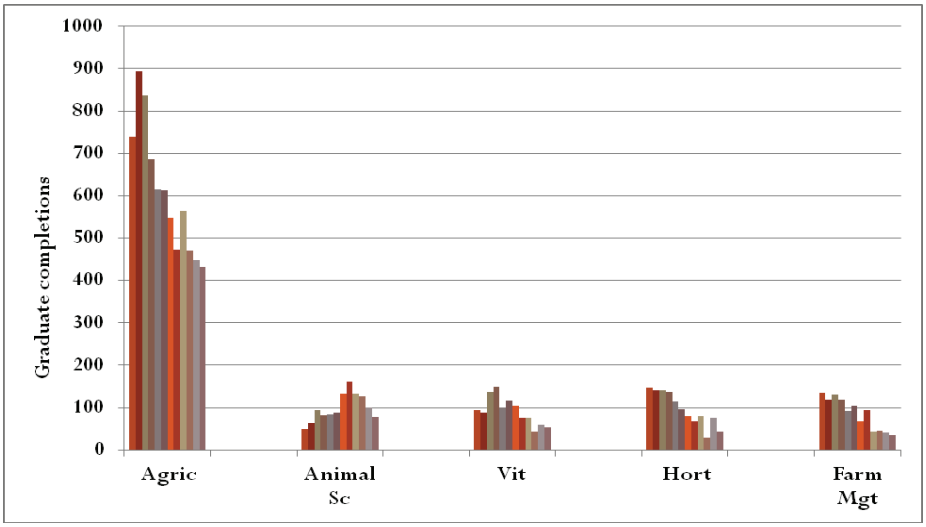

Figure 1. Annual graduate numbers (2002-2012) in agriculture and related areas (Pratley, 2012 updated)

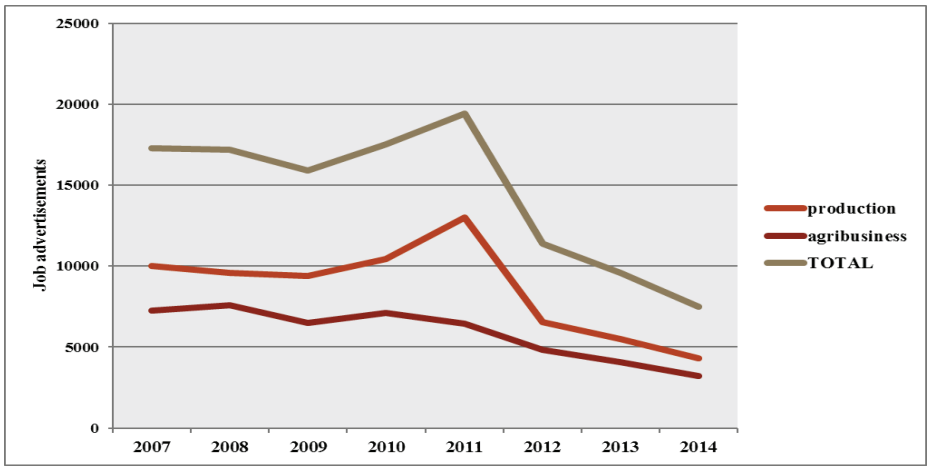

Figure 2. Job market trends for production and agribusiness based on advertisements in newspapers across Australia and on the internet for the period 2007-2014 (Pratley 2012, updated)

Data misinterpretation

During the roll out of information on the demand and supply of agricultural graduates, two questions became important:

1. Why were graduate shortages in agriculture not identified using the annual census data (enrolments and completions) provided by universities?
2. Why were school career advisers under the impression that there were no jobs in agriculture and therefore advising students out of such careers?

Access to official data did provide the explanation. As part of their reporting responsibilities to government, universities provide student data according to categories called Fields of Education (FoE). There are 12 FoEs, agriculture being FoE 05. The range of FoEs is given in Table 1. The codes in column 1 of Table 1 represent the broad or 2 digit codes. Each FoE is further broken down into components and so fields like agriculture can be separated from horticulture and animal production.

FoE 05 represents both agriculture and environmental graduates. The latter vastly outnumber agriculture graduates and so the combined data are more representative of environmental graduates than of agricultural graduates. For example, in 2010 the number of graduate completions from agriculture and environment courses was about 600 and 1500, respectively (Figure 3). Thus, inquiries on graduate completions for FoR 05 can be very misleading with respect to the agriculture discipline. The ACDA now uses the narrow 4-digit code for reporting graduate completions in agriculture. More detailed analysis is given in (Pratley 2015a).

This scenario repeats itself in relation to salary and employment status. New graduates are surveyed several months after graduation by Graduate Careers Australia, an agency of government. Responses received are classified according to FoE at the 2-digit code. Figure 4 shows that agriculture has around full employment (>90%) whereas environment hovers between 60 and 70% employment in recent years. When combined the data show around 70% employment. FoE 05 is thus largely representative of environmental graduates and unrepresentative of agriculture graduates.

These analyses help explain why, on the basis of this 'official' information, careers advisers have formed opinions that there are limited employment opportunities in agriculture. Further analyses of these data are given in (Pratley 2015b).

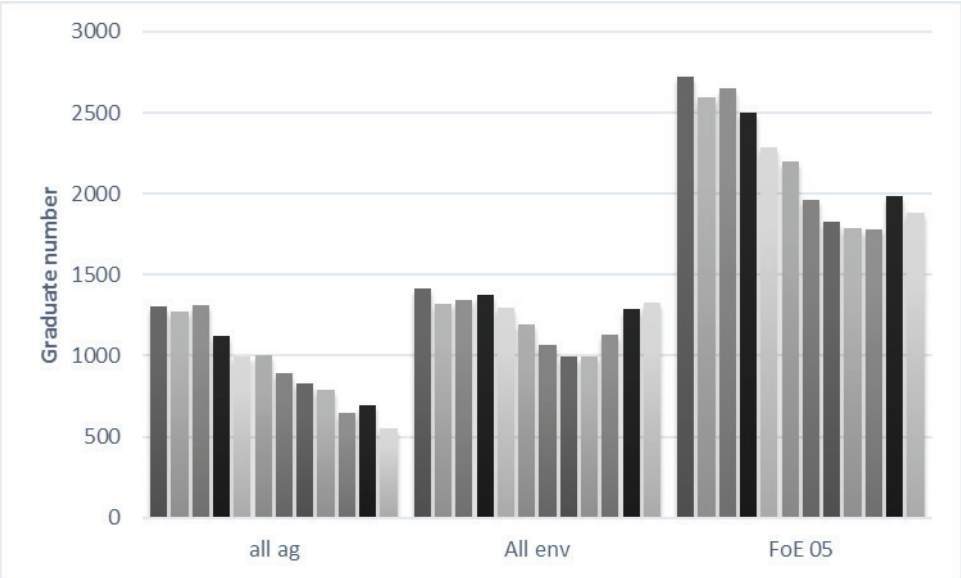

Figure 3. Annual graduate completions (2001 to2012) for agriculture and related courses, environmental courses and Field of Education 05 (Pratley 2015a).

Table 1. Agriculture and related sub-codes in the Field of Education (FoE) categorisation used in Australia.

Broad Code (2-digit)	*Narrow* (4-digit) and *Detailed* (6-digit) Code, where relevant
01 Natural and Physical Sciences	0107 Earth Sciences
	010709 Soil Science
	0199 Other Natural and Physical Sciences
	019905 Food Science and Biotechnology
02 Information Technology	-
03 Engineering and Related Technologies	0303 Process and Resources Engineering
	030307 Food Processing Technology
04 Architecture and Building	-
05 Agriculture, Environmental and related studies	**0501 Agriculture**
	050101 Agricultural Science
	050103 Wool Science
	050105 Animal Husbandry
	050199 Agriculture, n.e.c.
	0503 Horticulture and Viticulture
	050301 Horticulture
	050303 Viticulture
	0505 Forestry Studies
	050501 Forestry Studies
	0507 Fisheries Studies
	050701 Aquaculture
	050799 Fisheries Studies, n.e.c.
	0509 Environmental Studies
	050901 Land, Parks and Wildlife Management
	050999 Environmental Studies, n.e.c.
	0599 Other Agriculture, Environmental and related studies
	059901 Pest and Weed Control
	059999 Agriculture, Environmental and related studies, n.e.c.
06 Health	0611 Veterinary Studies
	061101 Veterinary Science
	061103 Veterinary Assisting
	061199 Veterinary Studies, n.e.c.
07 Education	-
08 Management and Commerce	0803 Business and Management
	080321 Farm Management and Agribusiness
09 Society and Culture	-
10 Creative Arts	-
11 Food, Hospitality and Personal Services	-
12 Mixed Field programs	-

Table 2. The percentage decline in graduate completions for Field of Education 05 and for agriculture from 2001 to 2010 (Pratley, 2015b)

Source	2001	2010	% decline
Undergraduate (UG) completions (FoE 05) (2 digit code)	2991	2207	26
Undergraduate (UG) agriculture completions (6 digit code)	886	413	53

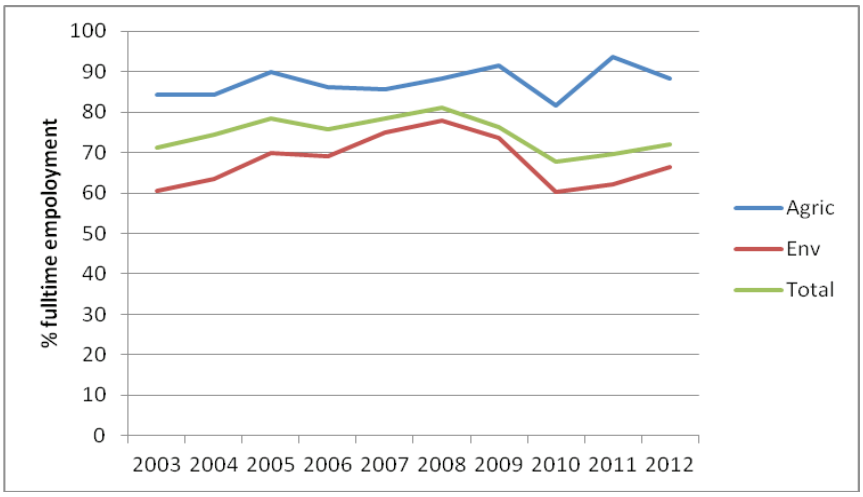

Figure 4. Comparison of full time employment of agriculture and environmental graduates, separately and together, in the Graduate Careers Australian surveys 2003 to 2012 (Pratley, 2015b)

The impact of the downturn on universities

While much has been written about the decline in numbers of agriculture *graduates* over the past decades and the shortages created in the market place, little has been reported about the *enrolment* numbers in agriculture in the university system during that period. Enrolments are important because they determine the level of funds received from the government. The funds in turn determine the viability of the university departments that offer the courses. Analysis of official enrolment data shows that in the period 2001-2012, undergraduate enrolments in agriculture courses declined from around 4000 in 2001 to around 1500 in 2012, or a 60% decline (Figure 5).

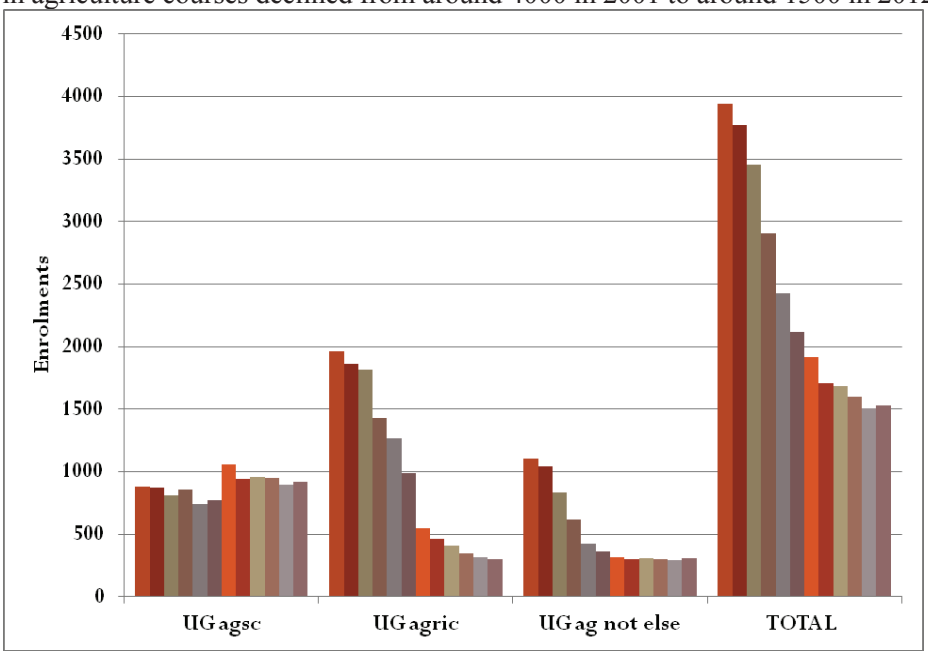

Figure 5. The annual decline (2001 to 2012) in undergraduate (UG) enrolments in agriculture courses in Australian universities (ACDA unpublished). Abbreviations: UG agsci, agricultural science; UG agric, agriculture; ag, agriculture courses not elsewhere reported.

Such decline (Figure 5) results in massive loss of income to those departments, with commensurate contraction of academic staff numbers and expertise. In 2012, a university received around $30,000 a year for a full-time student enrolled in agriculture. As a guide, the decline in enrolment numbers means that agricultural faculties received about $75 million less in 2012 compared with the baseline year 2001. Most of the funds received go into general university administration with about one third going to the teaching departments. Consequently, departmental funding has declined from around $40 million to $15 million. As a rule of thumb, there is a ratio of about 20 students per staff member and the enrolment downturn therefore is the equivalent of the loss of about 125 academic staff.

The consequences of staff contraction are many. University departments no longer have the range of specialist staff. The capacity to supervise practical skills development has also diminished. As such training is constrained there is less call for the associated facilities, which then are not maintained to levels required for compliance with workplace health and safety and are forced to close.

Unofficial reports by ACDA members indicate that there have been increases in intakes nationally over the years 2013 to 2015, albeit from a low 2012 base. There is a lag in response to this as institutions take a cautious approach to re-building teaching capability as there is a need for departments to become financially stable. It remains to be seen whether there is sustained growth but there are signs of new optimism in the higher education sector.

Towards professionalism and Agriculture Learning and Teaching Academic Standards

This episode in the evolution of the agriculture sector has been a wake-up call. There has been an increased urgency towards professionalising the industry – a focus on education and training, a desire to improve the image of the sector, a move towards social licence and greater engagement with future opportunities, challenges and needs. Universities have been an integral part of this increasingly professional approach and so the issue of quality in higher education is considered. Learning and Teaching Academic Standard (LTAS) Statements across several disciplines have been published, and are listed as reference points in the national standards framework developed by the Higher Education Standards Panel (Australian Government 2014). Graduates of agriculture and related sub-disciplines are employed in diverse roles, including but not limited to research, development and extension (R, D and E); primary production in the value chain; policy; finance and marketing; and media. As outlined above, recent inquiries by the ACDA and the state and federal Governments into higher education and skills training for agriculture and agribusiness has highlighted the importance of ongoing tertiary education in agriculture for Australia's economic prosperity. Universities must address the design, content and delivery of their agricultural curriculum to meet the needs of industry now and into the future.

The Agriculture Learning and Teaching Academic Standards (AgLTAS) were developed through a nationwide consultation with industry, graduates and academics and have been endorsed by the ACDA (Botwright Acuña *et al.* 2014a). The standards define the nature and extent of agriculture and also outline the key threshold learning outcomes (TLOs) for graduates. The standards include TLOs that closely reference those for the Science discipline (Jones *et al.* 2011): Knowledge, Understanding, Inquiry and Problem Solving, Communication and Personal and Professional Responsibility (Table 3). Together these represent what a pass-level graduate in agriculture should know, understand and be able to do upon graduation.

Although agriculture fits within Science, it also has technical, business, social and cultural aspects not captured in the Science TLOs. Agriculture is a multi-disciplinary area by its very nature and this is described in the standards. Industry input was vital in developing the national standards to ensure that agriculture graduates left university with the skills and knowledge needed by industry. The industry stakeholders who were consulted agreed that students needed to demonstrate highly developed problem solving and communication skills. Industry specific (vocational) knowledge was generally regarded as attainable during on-the-job training both during and after graduation. The issue of vocational training in agriculture at university is explored in more detail in Botwright Acuña *et al.* (2014b). The importance of undergraduates obtaining valuable on the job training through work-integrated learning or work experience is highlighted in the explanatory notes section of the standards statement. Furthermore, given the dynamic nature and

wide range of agricultural industries, the standards highlight that graduates need to be life-long learners and capable of undertaking continued professional development.

The new standards will inform the development and design of agriculture curricula delivered at Australian universities and will further promote agriculture as a career to encourage more young people into the growing industry. Greater engagement between universities and industry in curriculum design and cooperation between providers is necessary for curriculum rejuvenation (Dunne 2010; Bellotti 2012). For example, at the University of Tasmania, the standards have informed the proposed redevelopment of the three-year Bachelor of Agriculture degree program. The standards were mapped against the curriculum, which highlighted strengths in inquiry and problem solving that in some activities exceeded graduate level. Opportunities were identified to further strengthen some agribusiness-related topics to reinforce the commercial relevance of student learning outcomes. Higher education providers may choose to use these to demonstrate compliance with the proposed Higher Education Standards Framework in relation to learning outcomes and assessment.

Importantly, the standards will allow Universities to continue their delivery of unique content but enable students to have confidence that their degree is of a high standard. Higher education providers are encouraged to build on the standards as they design and deliver programs that reflect their particular strengths and priorities. They may do this by adding additional TLOs or by requiring the five TLOs to be met at a higher standard in their own organisation. If implemented as a reference point, the standards will support each higher education provider's autonomy, diversity and reputation.

Table 3. Threshold learning outcomes for agriculture. Extracted from the Agriculture Learning and Teaching Academic Standards (Botwright Acuña *et al.* 2014a)

Threshold Learning Outcomes for agriculture

Upon completion of a bachelor-level degree in agriculture or a related sub-discipline, graduates will, as a minimum, be able to demonstrate their knowledge and skills in the following areas:

Understanding agriculture

1. Demonstrate an integrative understanding of agriculture by:
   - 1.1. Explaining the role and relevance of agriculture and its related sciences, and agribusiness in society.
   - 1.2. Understanding the major biophysical, economic, social and policy drivers that underpin agricultural practice and how they contribute to practice change.
   - 1.3. Understanding how information is adopted and the context within which producers, processors and consumers, make decisions.

Knowledge of agriculture

2. Exhibit depth and breadth of knowledge of agriculture by:
   - 2.1. Demonstrating knowledge of the core sciences in the context of agriculture.
   - 2.2. Demonstrating broad generalist knowledge of relevant agricultural production systems and their value chains, with specialist knowledge in at least one area.
   - 2.3. Understanding how knowledge from different sub-disciplines within agriculture is integrated and applied into practice.
   - 2.4. Demonstrating a basic knowledge of economics, business and social science as they apply to agriculture.

Inquiry and problem solving

3. Critically analyse and address dynamic complex problems in agriculture by:
   - 3.1. Identifying contemporary issues and opportunities in agriculture.
   - 3.2. Gathering, critically evaluating and synthesising information from a range of relevant sources and disciplines.
   - 3.3. Selecting and applying appropriate and/or theoretical techniques or tools in order to conduct an investigation.
   - 3.4. Collecting, accurately recording, analysing, interpreting and reporting data.

Communication

4. Be effective communicators by:
   - 4.1. Understanding methods of effective two-way written and verbal communication with different audiences.
   - 4.2. Communicating with a range of audiences in an agricultural context using a variety of modes.

Personal and professional responsibility

5. Be accountable for their own learning and professional work by:
   - 5.1. Being independent and self-directed learners.
   - 5.2. Working effectively, responsibly and safely in an individual and team context.
   - 5.3. Demonstrating knowledge of the regulatory frameworks relevant to their specialist area in agriculture.
   - 5.4. Personally practising ethical conduct.

Conclusion

In 2007, higher education in agriculture was in a parlous state. Institutions were struggling to maintain agriculture programs. The industry sector faced a shortfall of graduates to take the sector forward into an era of opportunity. Through adversity comes strength and, with the combined efforts of many, the foundations of a firm future have been laid.

One particular outcome of these adverse circumstances was the formation of the ACDA. This brought the university sector together formally and enabled the study of graduate supply and demand through the compilation of data that hitherto had not been considered. The evidence clearly showed lack of supply of, and high demand for, agricultural graduates and helped provide the impetus for others to become involved in building interest in agriculture with schools and the community.

Data anomalies are now well understood but such discrepancies will continue to interfere with the data on enrolments and completions in agriculture and related disciplines unless the data are used appropriately. Categorisation of agriculture and environment into separate FoEs by government is highly desirable.

The decline in enrolments and associated contraction of funding for agricultural higher education has had a big impact to the extent that education delivery has been affected as staff numbers continue to decline, perhaps permanently. However the recovery phase, albeit slow and steady, is enabling newer and smarter approaches to courses. Agricultural industries have started to appreciate the need for more professionalism and universities are endeavouring to get their houses in order by addressing course standards nationally. With industry input, such standards will inform curriculum development and provide confidence that agricultural degrees are relevant and of high standard.

So, falling student enrolments and completions and the subsequent effect on teaching capacity over the last decade has driven a new dimension into agricultural education. There is greater ownership by all involved; there has been an image transition; awareness of career opportunities have been developed; and greater understanding has occurred of data and their interpretation. Taking advantage of the opportunities that lie ahead is in the hands of the agricultural sector, which we hope will be well supplied with new-age graduates. It is unclear where we would be, had there not been the thrust provided by the formation of the ACDA and its data focus.

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High rainfall zone grains: yield gaps, production trends and opportunities for improvement

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Abstract
There is growing recognition of the potential to increase crop production in the higher rainfall zones (HRZ) of southern Australia. We combined a survey of agricultural consultants, and an analysis of crop yields in order to (1) investigate recent trends in crop production, (2) quantify the gap between potential and actual crop yields, and (3) consider the factors thought to limit on-farm yields. The survey of agricultural consultants revealed that in the last 10 years there is a trend towards more cropping, an increased use of canola, adoption of dual purpose crops, and advances in the adaptation of cultivars to the HRZ. In Victoria, NSW and South Australia the long-term water-limited potential yield, estimated by modelling, consultants and experimental measurements, for HRZ wheat and canola was 5-6 and 2-3 t/ha for a decile 5 season. The equivalent values for WA were 4-5 and 2-3 t/ha, where yields were less responsive to good seasons than in the other states. There was a large gap between APSIM simulated potential yield and farmer-realised yields, however the top performing farmers were achieving close to the water-limited potential yield. In all regions, there appears to be scope for large gains in yield and productivity benefits by encouraging the below-average cropping farmers to adopt the practices and behaviours of the above-average farmers, such as being prepared to pay for inputs, more timely sowing, weed and disease control, and N-topdressing.

Key Words
High rainfall zone, crop, technology, wheat, canola

Introduction

In the last decade, there has been a growing recognition of the potential to increase crop production in the higher rainfall zones (HRZ) of southern Australia. The comprehensive review of Zhang et al. (2006) highlighted the potential to increase grain production in the HRZ, and discussed the biophysical constraints to crop production that would need to be addressed to underpin expansion. They also emphasised the issue of perceived poor adaptation of the then currently-grown crop cultivars to HRZ. Since this 2006 review, there has been a trend towards more cropping in the HRZ, an increased use of canola in rotations compared to the medium and low rainfall zones, and adoption of dual purpose (grazing and grain production) use of cereals and canola. In the last 10 years a substantial program of research, development and extension specifically focussed on the HRZ has been conducted, funded by the Grains Research and Development Corporation, state and federal government agencies, and universities. This program has examined agronomic and cultivar adaptation issues, soil and climatic constraints and more recently environmental concerns such as nutrient and pesticide runoff, acidification, and biodiversity threats to agricultural expansion. In order to inform directions for further research in the HRZ, there is a need to assess the impact of this recently completed research and reassess crop production trends and practices in the HRZ, against a background of changing trends in climate, improved cultivars and new management systems, and contemporary perceptions regarding the constraints to crop production in the HRZ.

Therefore in order to examine the current status of HRZ cropping systems and identify opportunities for further research, development and/or extension programs, we combined a survey of agricultural consultants and an analysis of crop yields in order to (1) investigate recent trends in crop production, (2) quantify the gap between potential and actual crop yields, and (3) consider the factors thought to limit on-farm yields.

Methods

We collected data on current on-farm crop yields, constraints to increasing yield, and the scope for increasing production on-farm. Fifteen farm consultants from New South Wales (NSW), Victoria, South Australia (SA) and Western Australia (WA) were interviewed about trends in grain production in the last 10 years, perceived constraints to production, and future needs for RD&E. They also nominated typical grain yields produced in different seasons by farmers varying in their level of management skill. The consultant's views of on-farm yields was compared with potential yields observed in high-yielding experimental conditions from 2009-2013 and previously published estimates generated from simulations using the APSIM model (Bell et al. 2014, Lilley et al. 2014).

Results and Discussion

Potential yield

According to consultant estimates, the above-average farmers in Australia's HRZ are achieving yields between 4.5 and 6 t/ha for winter cultivars of wheat in a decile 5 season in NSW, Victoria and SA (Figure 1). These yields are consistent with long-term simulations for winter cultivars (Bell et al. 2014), who simulated lower yields for spring cultivars (approx. 0.5 t/ha less) due to their shorter season length and hence lower yield potential. Moreover, experimental plot yields (Table 1) confirm that over the long-term between 5 and 6 t/ha is a reasonable yield expectation for wheat crops that are being managed close to their water-limited potential. In high-yielding seasons (timely sowing, growing season rainfall >350 mm) observed experimental yields suggest that yields of nearly 10 t/ha are possible using cultivars of winter wheat, as also observed in simulation studies (Bell et al. 2014, Lilley et al. 2014) where a 25% yield advantage was associated with winter wheat cultivars over shorter season spring types. At the other end of the distribution for yield expectations, experimental yields (Table 1) and consultant estimates for above-average farmers (Figure 1) suggest that wheat yields of 3 t/ha could be expected from well managed crops in a decile 2 season (equivalent to about 200 mm growing season rainfall). These results suggest that leading farmers in the HRZ are growing crops close to the water-limited potential. Results of the consultant survey indicated that consultants primarily attributed these higher yields to the farmers' (1) preparedness to pay for inputs, (2) timeliness of operations, and (3) focus on effective weed, pest and disease control. The results also raise the question whether a lack of adapted germplasm remains one of the principal constraints to exploiting the potential yield in the high rainfall zone.

Table 1 Summary of grain yields of wheat and canola measured under experimental conditions by the authors in the high rainfall zone of four states. GSR = growing season (April-November) rainfall.

State	N	Yield (t/ha)		Sowing date		GSR (mm)	
		Mean	Range	Mean	Range	Mean	Range
				Wheat			
NSW	18	6.1	0.1 - 8.7	12th April	11 Mar - 24 May	398	239 - 883
VIC	46	4.8	2.4 - 7.3	24th May	5 May - 6 July	434	216 - 584
SA	14	6.3	2.3 - 9.3	2nd June	16 May - 25 June	514	276 - 659
WA	8	4.8	3.4 - 5.9	20th May	9 May - 30 May	400	292 - 526
				Canola			
NSW	25	3.5	0.3 - 5.7	13th April	11 Mar - 24 May	360	162 - 572
VIC	18	2.0	0.7 - 3.0	25th May	2 May - 3 July	457	216 - 622
SA	13	2.8	2.1 - 3.8	2nd June	14 May - 9 Jul	415	254 - 544
WA	8	3.0	2.5 – 4.0	18th May	9 May - 25 May	433	250 - 504

There is similar consistency for canola yields achieved by above-average farmers in the HRZ across consultant estimates (Figure 1) and experimental yields (Table 1) with ca. 2.5 t/ha to be expected in a decile 5 year, declining to 1 t/ha in a decile 2 and up to 3.5 t/ha in a decile 8. However simulated estimates (Lilley et al. 2014) of long-term potential yield were 3.5-4 t/ha, noticeably higher than consultant estimates for a decile 5 year. It is therefore possible that even above-average farmers are not yet achieving the water-limited yield potential in above-average seasonal conditions, perhaps due to disease, inadequate nitrogen application or waterlogging. In our dataset of experimental yields we recorded numerous examples of canola yields of >4 t/ha in NSW, as did Christy et al. (2013).

The notable exception to the national trend described above was the lower estimates of water-limited yield potential for WA. Whereas in Victoria, NSW and South Australia the long-term yield potential for wheat and canola was 5-6 and 2-3 t/ha, the equivalent values for WA nominated by consultants were 3 and 1.5 t/ha. These estimates were some way below those recorded in experimental plots (5 t/ha for wheat and 3 t/ha for canola, Table 1) and simulations (4.5 t/ha for spring wheat and 3.5 t/ha for spring canola, Lilley et al. 2014), and it is possible that the consultant estimates were biased in some way, perhaps by drier recent seasons, whereas the long-term simulations and experimental yields spanned a longer climate record.

Yield gap

The results of the consultant survey and comparisons with experimental yields indicate the existence of a sizable yield gap between above average farmers and below-average farmers. In high rainfall seasons, the scope for improvement was 1-3 t/ha for wheat and 0.5-1.5 t/ha for canola, the difference between the below and above-average farmers. The yield gap was smaller in poor seasons (i.e. decile 2) when seasonal factors are the limiting factor to production rather than agronomic management.

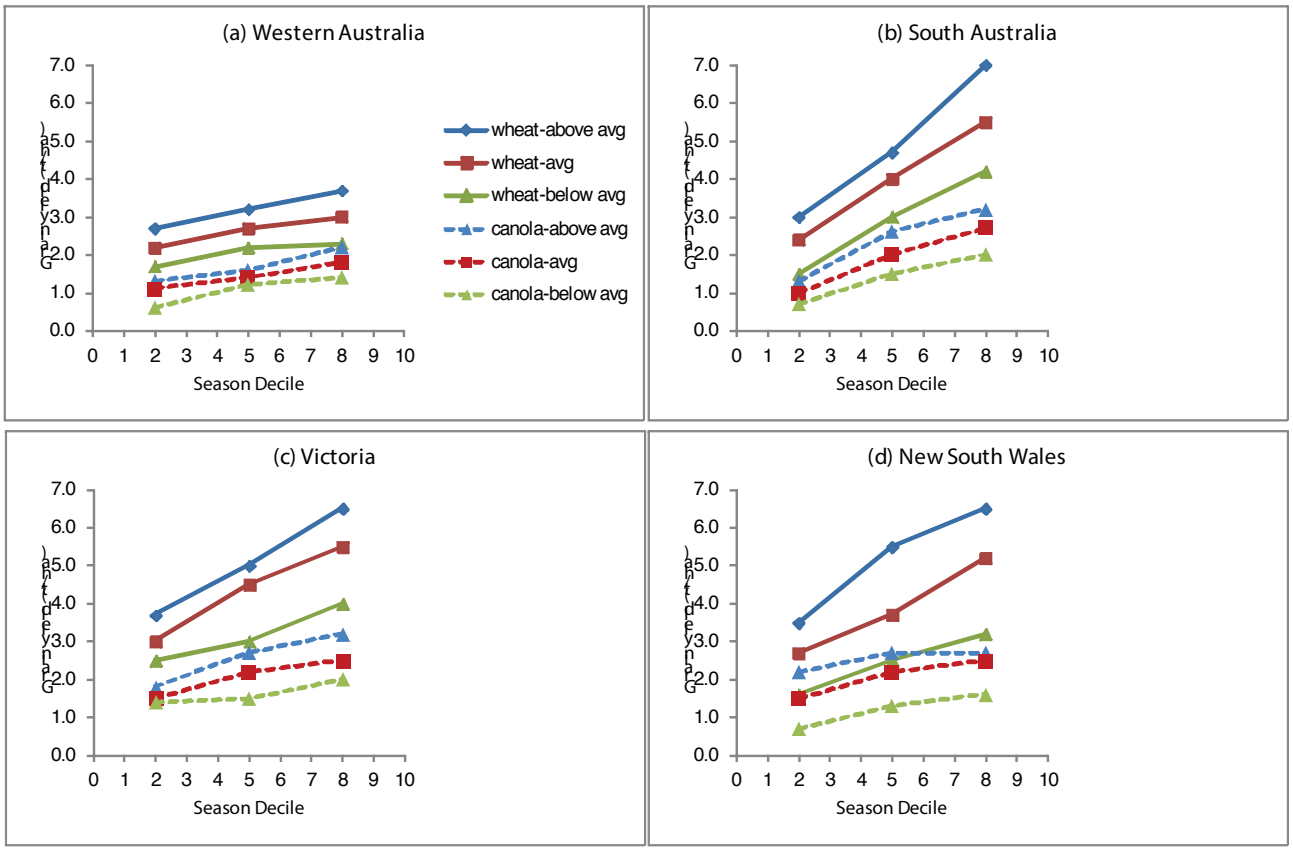

Figure 1: Consultant estimates of grain yields produced of wheat and canola for below-average, average and above-average performing farmers as a function of season decile. Data are averages collected from consultants in (a) Western Australia (n=4), (b) South Australia (n=3), (c) Victoria (n=4), (d) New South Wales (n=4)

Consultants had consistent views on the reasons for poor performance by the bottom one-third of grain producers in the HRZ. A key theme across consultants in all four states was that poor timeliness of key operations was a major factor in the poor performance of below-average farmers. Improved timeliness of

these key operations (nominated as sowing, weed and disease control, and N-topdressing) could reduce some of the yield gap we have quantified here. The consultants also highlighted that above average farmers tend to be more are organised and efficient, achieve more effective weed control, are more willing to invest financially on inputs, and keep or have access to well maintained machinery for sowing and harvesting. In all regions, consultants saw the scope for large gains in yield and productivity by encouraging the below-average cropping farmers to adopt these practices and behaviours of the better farmers. Reasons for the differences in behaviour must take account of the whole-farm socio-managerial context. For example, lack of timeliness from a crop production perspective may be a consequence of compromises that have to be made on a mixed farm around pasture and livestock management. A greater understanding of this may help identify ways to maximise farm production and profitability, and not that of grain alone. The issue of greater timeliness is particularly pertinent when considering the opportunities for early sowing shown in Bell et al. (2014) and Lilley et al. (2014). They showed that in at least 50-60% of years there exists an opportunity to sow between mid-April and mid-May, and in at least 30-40% of years there is an opportunity between 1 March and 15 April. In moving the average date of sowing earlier, potentially with longer-season cultivars, will require higher levels of inputs to exploit the greater water-limited potential (Kirkegaard and Hunt 2010).

A smaller number of consultants were also of the opinion that recent advent of widespread grain production in the high rainfall zone means that the skill and knowledge base within the HRZ is smaller than that found in more established grain production regions. There was also a view that a lack of up-to-date infrastructure and services is constraining the industry's ability to adopt new technology. The high rainfall zone is characterised by smaller farms, often with smaller paddocks and in undulating terrain, and may be a factor in constraining the adoption of some technologies such as controlled traffic and variable rate technology that require larger-scale areas to make them profitable. However there have been no definitive studies to identify the role that infrastructure and farm configuration/size play in improving production and productivity on grain producing farms.

Conclusions

The results of this review and analysis suggest a number of opportunities for R, D and E in the high rainfall zone to lift crop yields. Firstly, given the sizable gap between the performance of above- and below-average farmers, there is a case for development and extension to identify causes of lower yield by poor-performing farmers, the socio-managerial context for poor timeliness by HRZ crop producers, and on-farm demonstrations to show the benefits of improved agronomy. Secondly, the promising yields from winter types of wheat and canola suggests that research is warranted to better understand the yield potential possible with new combinations of genotype, and environment and the management inputs required to express yield potential, particularly nitrogen. Thirdly, crop yields in the HRZ of WA do not respond as well as those in other states to water supply in wet seasons, hence research and development is required to identify the reasons for these differences. Finally, the HRZ is clearly still a landscape in transition. Future decisions about R, D and E will be better informed if trends in farm-level production, management practices and attitudes are monitored as the transition toward increased grain cropping continues in the HRZ.

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Drivers of high-yielding irrigated wheat production

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Abstract
Irrigated wheat has the potential to consistently yield over 10 t/ha with optimum management. Growers however are often achieving much lower yields. Yields of 1520 t/ha have been obtained in ideal conditions overseas but Australia's climate significantly reduces yield potential. Barriers to consistent 10 t/ha yields for irrigated wheat were identified in trials conducted throughout south-eastern Australia. The trials investigated the effects of variety, plant population and nitrogen management on irrigated wheat grain yield. Preliminary results are presented from the first of three years' trials as part of the 'Southern Irrigated Cereal and Canola Varieties Achieving Target Yields' project. Data show the significant effect that variety selection and management can have on productivity. Variety had a significant effect on grain yield at both Murrumbidgee trial locations. At Leeton six of the 12 varieties included in the trial achieved over 10 t/ha with Suntop and Chara both yielding 10.32 t/ha followed by Kiora, Merinda and Corack, and Lancer. At Coleambally, Suntop (7.33 t/ha) was again the highest yielding variety followed by Lancer and Chara. EGA Gregory yielded lowest at Leeton (8.84 t/ha) followed by Mace (9.05 t/ha) and Dart (9.53 t/ha). The three lowest yielding varieties at Coleambally were Dart, Bolac and EGA Gregory, with 5.86 t/ha, 6.60 t/ha and 6.72 t/ha, respectively. A plant population of 140 plants/m^2 yielded significantly higher than 210 plants/m^2 at Leeton but there was no effect of plant population at Coleambally. Applying the bulk of nitrogen at booting stage significantly increased yield at Leeton compared to applying the bulk of nitrogen at sowing. At Coleambally, there was no difference in yield between applying most nitrogen at the first node stage and most nitrogen at booting. Delaying nitrogen application significantly increased grain protein.

Key words
Irrigated, wheat, variety, agronomy, high yielding, winter cropping

Introduction
Recent research identified significant potential for increased production and profitability of irrigated cereals (Milgate 2007). The importance of correct varietal selection for dryland crops is well documented; however, the best performing varieties in dryland systems may not be equally successful in irrigated systems. Identifying the best wheat varieties, and agronomic management, for irrigated systems is essential to consistently achieve high potential yields.

Methods
The trial was conducted at two locations – Leeton and Coleambally. It evaluated the effect of variety, plant population and nitrogen management on grain yield and grain quality (Tables 1 and 2). Varieties are shown in Figure 1. Plant populations included low (140 plants/m^2) and high (210 plants/m^2) treatments. Coleambally and Leeton trials were both a 3 replicate randomised block design. Data were analysed spatially with Genstat 17th edition.

Table 1. Nitrogen treatments at the Leeton and Coleambally trial sites.

Nitrogen treatments:		Nitrogen applied (kg N/ha)		
Site	*Treatment*	*At sowing*	*1st node*	*Booting*
Leeton	Early N	90	50	30
	Late N	30	50	90
Coleambally	Early N	90	60	20
	Late N	90	20	60

Table 2. Soil, paddock history, fertiliser, sowing and cultural details at the Leeton and Coleambally trial sites.

Detail	Leeton	Coleambally
Soil type	Self-mulching medium clay	Grey lightmedium clay
Previous crop	Barley (2013)	Barley (2013)
Soil starting N	55 kg N/ha	65 kg N/ha
Pre-sowing fertiliser	150 kg/ha of MAP (15 kg N/ha)	150 kg/ha of MAP (15 kg N/ha)
N treatments	370 kg/ha of urea (170 kg N/ha)	370 kg/ha of urea (170 kg N/ha)
Soil N mineralised	45 kg N/ha	45 kg N/ha
(estimation)	*Total N budget – 285 kg N/ha*	*Total N budget – 295 kg N/ha*
Sowing date	7 May 2014	14 May 2014
Row spacing	260 mm	260 mm
Irrigation	Autumn pre-watering – 2.2 ML/ha	Autumn watering-up – 1.2 ML/ha
	Three spring irrigations – 1.1 ML/ha x 3	Two spring irrigations – 1.3 ML/ha x 2
	Total – 5.5 ML/ha	Total – 3.8 ML/ha
Fungicides	Tilt® at 250 mL/ha (by boom)	Orius® at 150 mL/ha (by aircraft)
	Orius® at 150 mL/ha (by boom)	
Herbicides	Achieve™ at 400 mL/ha	MCPA at 1.25 L/ha (by boom)
	MCPA at 1.25 L/ha (by boom)	Lontrel™ at 70 mL/ha (by boom)
	Lontrel™ at 70 mL/ha (by boom)	
Harvest date	9 December 2014	10 December 2014

Results

Variety

Variety had a significant effect on grain yield at both Leeton and Coleambally. Suntop and Chara (10.32 t/ha) were the highest yielding varieties at Leeton. Grain yield of these varieties was not significantly different to Kiora, Merinda and Corack which all yielded over 10 t/ha at Leeton. EGA Gregory (8.84 t/ha) had the lowest yield, significantly lower than all other varieties except Mace (9.05 t/ha) at Leeton (Figure 1).

Suntop (7.33 t/ha) was the highest yielding variety at Coleambally but not significantly different to Lancer, Chara and Mace. Dart (5.86 t/ha) had the lowest yield. Bolac (6.00 t/ha) was the second lowest in yield, similar to EGA Gregory, Impala and Merinda (Figure 1).

Grain yields at Coleambally were significantly lower than Leeton which was likely due to moisture availability from irrigation scheduling. The Leeton site received 2.2 ML/ha during watering up while Coleambally received only 1.2 ML/ha. Additionally, Leeton received three spring irrigations (total of 5.5 ML/ha for the season) and Coleambally received two spring irrigations (total of 3.8 ML/ha for the season).

Grain protein was affected by variety at both locations. Dart had the highest protein content (12.7%) at Leeton, followed by Wallup (12.4 %) and Lancer (12.2 %). Impala had the lowest grain protein content (10.9%). At Coleambally, Dart and Lancer had the equal highest protein content (12.1%) (Figure 1). EGA Gregory, Mace and Impala protein contents varied greatly between the two locations (Figure 1).

Variety also significantly affected plant establishment, tillering, plant height, number of heads, lodging, normalised difference vegetation index (NDVI), screenings, thousand grain weight (TGW), test weight and harvest index at both trial sites (data not shown).

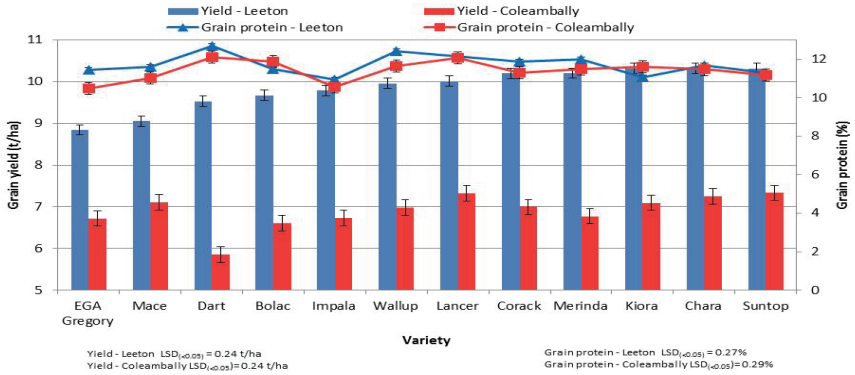

Figure 1. Wheat grain yield and protein content of varieties averaged across all nitrogen and plant density treatments at Leeton and Coleambally 2014.

Nitrogen management

Nitrogen (N) management significantly affected grain yield when averaged over all varieties at Leeton but not at Coleambally. The late N treatment yielded 10.00 t/ha, significantly higher than the early N treatment which yielded 9.70 t/ha. There was also a variety by N interaction effect on grain yield (Figure 2). Mace had the largest response of 0.94 t/ha from early to late N application, followed by Kiora (0.71 t/ha) and Bolac (0.68 t/ha). In addition Lancer, Gregory and Chara also increased grain yield in response to late N applications.

Kiora (10.67 t/ha) was the highest yielding variety for the late nitrogen treatments at Leeton and was statistically similar in grain yield to Chara, Merinda and Suntop. Corack (10.31 t/ha) was the highest yielding variety in the early N treatments at Leeton. This was statistically similar in yield to Suntop, Chara, Merinda and Wallup. Mace (8.58 t/ha) was the lowest yielding variety in the early nitrogen treatments.

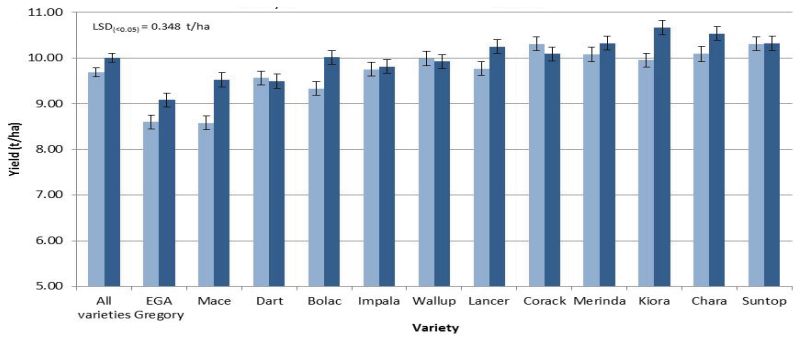

Figure 2. Wheat grain yield of nitrogen treatments averaged across all plant densities at Leeton 2014.

The late N treatment had an average grain protein content of 11.8% which was significantly higher than the early N treatment (11.3%) across all varieties, plant populations and locations. Late N application at Leeton also increased thousand grain weight but reduced tiller number, head number, lodging and NDVI.

Plant population

Plant population and the variety by plant population interaction significantly affected grain yield at Leeton but not Coleambally. At Leeton, the low plant population (140 plants/m2) had a grain yield of 9.90 t/ha which was higher than the high plant population (210 plants/m2) which was 9.80 t/ha (Figure 3).

EGA Gregory had a significant decrease in grain yield (0.62 t/ha) when the plant population increased from 140 plants/m2 to 210 plants/m2. In contrast, Chara had a significant increase in grain yield (0.35 t/ha) when the sowing rate was increased.

Kiora (10.40 t/ha) was the highest yielding variety for the low plant population (140 plants/m2). This was not significantly different to Corack, Merinda, Suntop, Chara and Wallup. Mace was the lowest yielding variety with a grain yield of 8.96 t/ha. Mace and EGA Gregory both had significantly lower grain yield than all other varieties for the low plant population (Figure 3). Chara (10.49 t/ha) was the highest yielding variety in the

high plant population treatment (210 plants/m2). This was not significantly different to Suntop and Kiora. EGA Gregory was the lowest yielding variety (8.53 t/ha) and was significantly lower in yield than all other varieties for the high plant population.

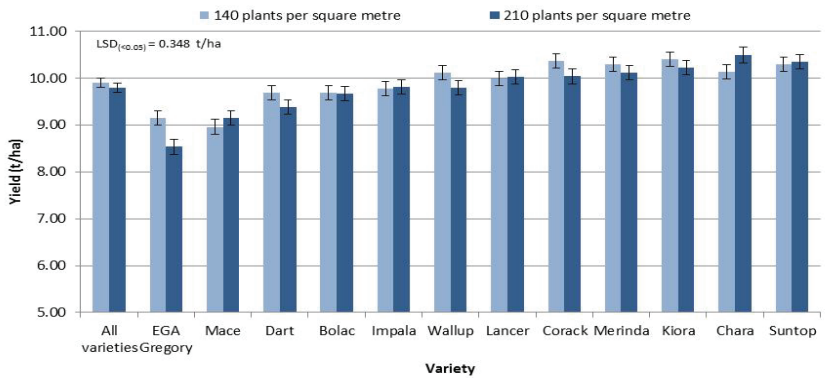

Figure 3. Wheat grain yield of plant population treatments averaged across all N treatments at Leeton 2014.

Conclusion

The wheat trials demonstrated that variety is a major driver of high yields. Suntop and Chara were in the highest yielding bracket at both trial sites. Lancer and Kiora also performed well, both achieving high grain yield at both sites while Mace, Dart and EGA Gregory had the lowest yields at both trial sites.

Timing of nitrogen application had an overall significant effect on grain yield and grain protein. At Leeton, applying most nitrogen (82%) after the first node stage significantly increased grain yield and grain protein compared with applying most nitrogen (53%) pre-sowing. Improved yields through application of late N were driven by increased tillering, increasing head numbers, reduced lodging and increased thousand grain weight. At Coleambally, no difference was observed in grain yield between the different topdressing timing treatments.

A lower wheat plant population (140 plants/m^2) resulted in higher yields across all wheat varieties when compared to a higher plant density (210 plants/m^2) at Leeton. Corack, Dart and Wallup had a yield advantage at the lower plant population whereas Chara and Mace performed better at the higher population. Individual varietal responses to plant population should be considered.

Acknowledgements

The support of Glenn Morris, Paul Morris and Patrick Dando for assistance with trial management, and the Bellato family for hosting the Coleambally trial on their property is acknowledged. This trial is part of the 'Irrigated cereal and canola varieties achieving target' yields project jointly funded by NSW Department of Primary Industries and GRDC (Project DAN00198; 2014–2017).

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Crop yield potential limited by nutrient status in the high rainfall zone of Southern Australia

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Abstract
The High Rainfall Zone (HRZ) of southern Australia has high yield potential; however, current on-farm yields are often only half to a third of these values averaging 2.7 t ha^{-1} for wheat and 1.4 t ha^{-1} for canola. The unrealised potential appears to be due to low nutrient status. A range of data sets have been compiled to help identify the extent of nutrient deficiencies (N, P, K and S) in different HRZ regions. This information along with a current experimental program being conducted in the HRZ will help advance the biophysical modelling and economic analyses of nutrient use and help determine the levels of fertiliser required to boost wheat and canola profits on individual farms.

Key words
Crop nutrient requirement, crop modelling, economic analysis

Introduction

The HRZ of southern Australia has high grain yield potential with estimates ranging from 4.5 t ha^{-1} in Western Australia to 11 t ha^{-1} in south eastern Australia and 3 t ha^{-1} to 5 t ha^{-1} for canola depending on location (Acuña *et al*. 2011; Riffkin *et al*. 2012; Christy *et al*. 2013). However, current on-farm yields are often only half to a third of these values averaging 2.7 t ha^{-1} for wheat and 1.4 t ha^{-1} for canola. With the introduction of superior varieties with high yield potential and new management practices, greater inputs will be required to achieve such potential. Management of high input systems can be complex and risky with high upfront costs from fertiliser, seed, fungicides, pesticides, herbicides and possibly plant growth regulators. For example, under experimental conditions at Hamilton where inputs have been very high, canola yields have exceeded 7 t ha^{-1}. Such a crop removes approximately 280 kg N, 45 kg P, 65 kg K and 70 kg of S per hectare in the grain. Fertilising to these levels requires considerable up-front costs and is 3 to 4 times greater than those currently applied on-farm.

Balancing all inputs including fertiliser is essential for optimizing yields, increasing profits, and improving the efficiency of fertilizer use. Nitrogen (N) may be the most common limiting nutrient, however, without balanced nutrition, fertilizer N applications may be less efficient and part of the fertilizer investment is wasted. Additionally, due to risks associated with the return on investment of applying much higher inputs than is currently applied, there needs to be greater understanding of the risks and economics of crop response based on each additional unit of input applied. Previous analyses of Christy *et al*. (2015) have highlighted how the costs and risks of the management of nutrients can be better managed to consistently achieve high yields in the HRZ of southern Australia. This paper summarises gaps in current knowledge that limit the ability of growers and advisers to confidently project input requirements and associated risks for crops with high yield potential in the HRZ. Specifically, we provide recommendations for an experimental and modelling approach that can more accurately project demands whilst also quantifying the economic risks associated with applying inputs to crops so they may attain their high yield potential.

Methods

Grain yield data sourced from National Variety Testing (NVT) trials 2002-2012 at Birchip, Horsham, Rutherglen, Hamilton, Streatham and Inverleigh was used to analyse nutrient limitation on yield through mapping across Victoria. The maps created for this paper use data sourced from National Land and

Water Resources Audit (Available at http://nrmonline.nrm.gov.au/catalog/mql:892) and are categorised as responsive using the critical values for each nutrient determined by the Audit and the Better Fertiliser Decision for Crops National Database (GRDC 2014).

What is preventing this yield potential from being reached?
An analysis of data from NVT Trials over the past 10 years in Victoria shows grain yields for both wheat and canola to be generally below the projected potential in the HRZ. A comparison of the grain yields achieved by control varieties and new varieties shows that greater gains are being made towards higher grain yields in the HRZ than in the low and medium rainfall zones (Figure 1). This is even more evident when experiments are treated with fungicides to eliminate foliar disease as a constraint to grain yield (shown in Figure 1 as HRZ 2012). The skewed distribution of NVT crop varieties exceeding the control is a demonstration that new crop varieties suited to the HRZ are lifting the potential grain yield compared to the established wheat growing areas where new varieties show limited improvement in grain yield. Smaller gains in the established wheat growing areas is due to much of the genetic potential already being realised thanks to the relatively long history of cereal breeding for that area.

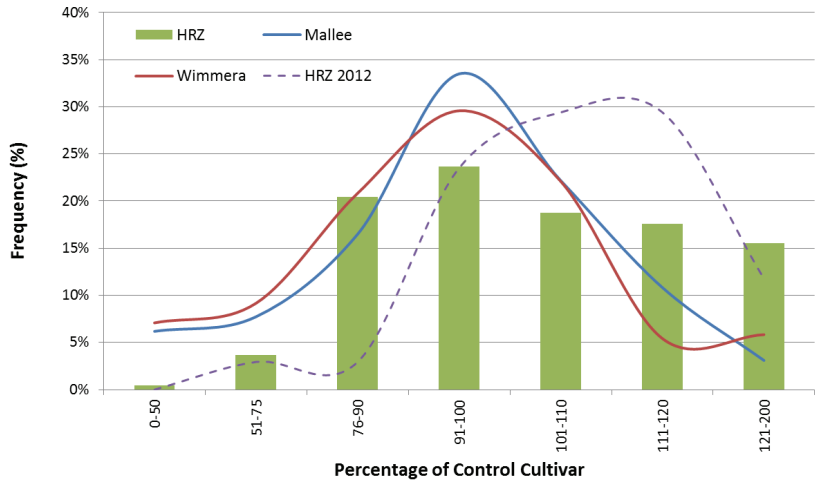

Figure 1: Measured grain yields relative to a control variety (100%) at NVT sites. Selected sites represent a rainfall zone: low rainfall zone (Birchip) n =194, medium rainfall zone (Horsham) n=240, HRZ (Hamilton & Streatham) n=245 (2002 – 2012). HRZ 2012 shows field experiments treated with fungicides in 2012 (Inverleigh and Rutherglen) n=34.

The protein levels of wheat from these NVT trials (2002–2012, excluding 2006 and 2009 due to crop failure) provide evidence of sub-optimal nutrition. Analysis of this data found grain protein (GP) levels (minimum GP target 13%) to be overall low with 27% of samples having levels less than 10% GP, 41% having less than 10.5% GP, 74% less than 12% GP and 87% less than 13% GP. These low GPs are the result of fertiliser application consistent with grower practice and suggest that N may have been limiting in these field experiments. Screenings were also low indicating that the field experiments were not adversely affected by crop disease or frost. This is important as NVT varieties sown in Victoria were not routinely treated with fungicides to control foliar disease until 2010.

Although NVT grain yield data is generally achieving grain yields higher than crops grown nearby, they should not be seen as representing the yield potential of the HRZ due to suboptimal sowing dates and the conservative use of inputs principally nitrogen fertilisers at NVT sites, (Jon Midwood, CEO Southern Farming Systems, pers. comm.). The gap between grain yields achieved in NVT and the potential that can be achieved by increasing inputs is demonstrated by comparing the grain yields achieved by neighbouring experiments containing similar varieties (Figure 2). The rationale for conservative use of inputs by NVT sites is that they are seeking to represent current farmer practice to allow direct comparison with nearby crops. This strategy however is a poor predictor of yield potential, with Southern Farming System (SFS) trial results almost doubling those of the NVT sites and achieving the projected yield potential for the HRZ of 8 t ha^{-1}. However, based on the light, water and nutrient resource availability in the HRZ it is believed that the present maximum wheat yield of 8 t ha^{-1} can be raised to at least 12 t ha^{-1} through the provision of adequate crop inputs to crop ideotypes specifically bred for the HRZ environment (Sylvester-Bradley et al. 2012).

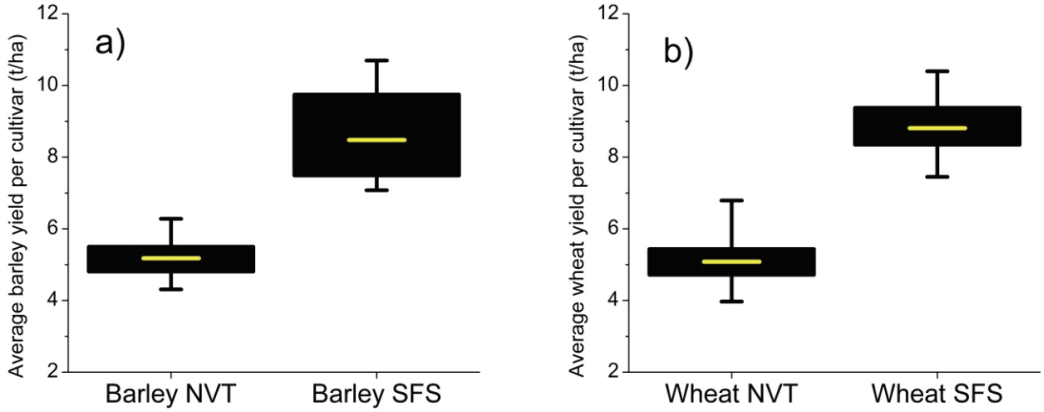

Figure 2: Box and whisker plot (maximum, 75 percentile, mean, 25 percentile, minimum) average 2013 grain yields per variety at National Variety Trials (NVT) site and nearby Southern Farming System (SFS) site for a) barley (NVT site at Teesdale (n=22) and SFS site at Inverleigh (n=13)) and b) wheat (NVT site at Streatham (n=32) and SFS site at Westmere (n=22))

Current nutrient status in the HRZ

An analysis of the soil nutrient status across the HRZ of southern Australia indicates a range of different nutrient deficiencies in different regions. Soil test data from the National Land and Water Resources Audit (NLWRA) show that nutrient status varies, with large areas likely to be responsive to the application of phosphorus (P), potassium (K), sulphur (S) and lime (Figure 3). Additionally, the spatial pattern of where each nutrient is most limited varies considerably across the HRZ. Data collated by Incitec Pivot (soil tests 2010 for the SA and Vic HRZ) indicate that these spatial images are conservative in their projection of potential crop nutrient response. The Incitec Pivot data showed that 50% of the soils have a pH_{ca} of less than 5.0, 40% of soils were low in K and S, and soil and tissue tests showed micronutrient deficiencies of 20% for copper (Cu) and 10% for zinc (Zn).

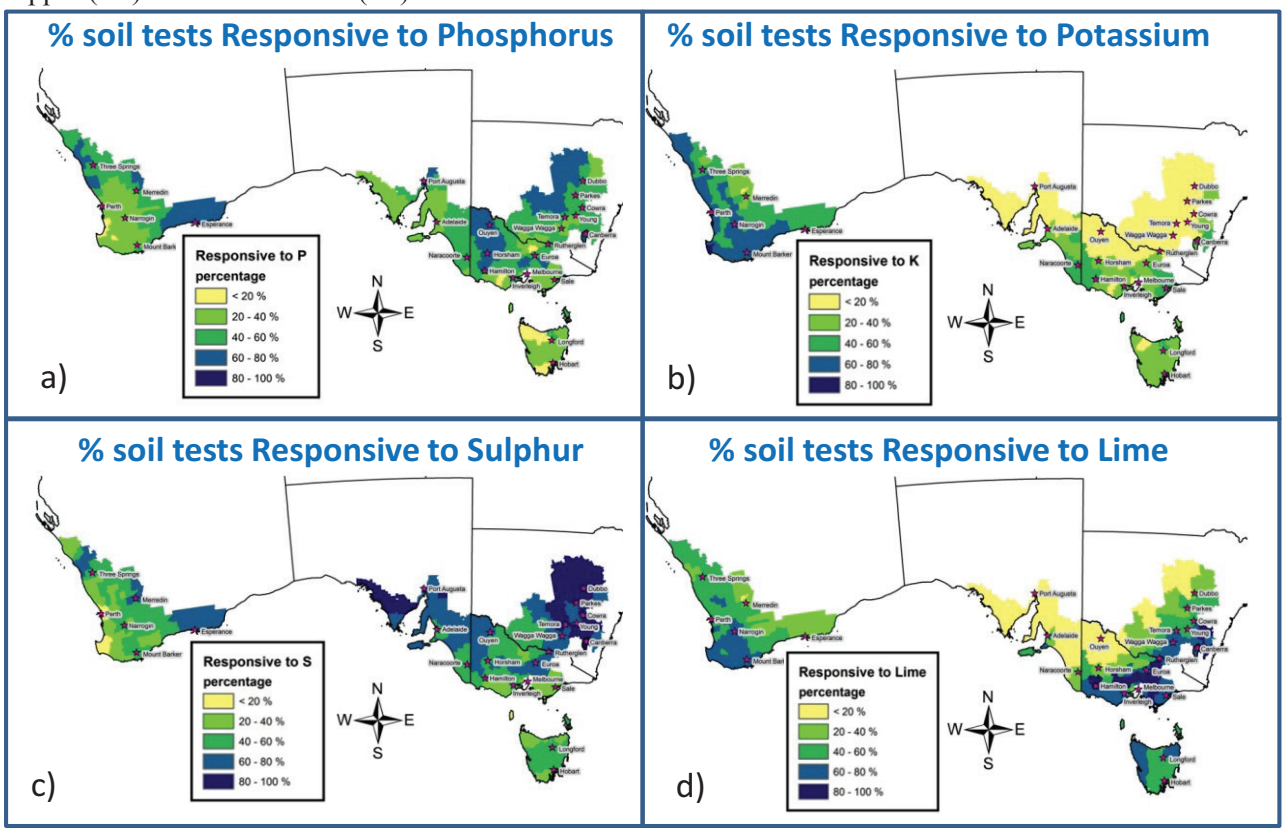

Figure 3: Spatial distribution of the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') to a) phosphorus b) potassium c) sulphur and d) lime based on the soil test data collated as part of the NLWRA nutrient database. (Available at http://nrmonline.nrm.gov.au/catalog/mql:892)

Overcoming the nutrient limitation

A different approach is needed to previous modelling efforts, which have focused specifically on yield response to additional nitrogen applications. This new approach should consider a balanced fertiliser assessment of N, P, K and S and their differential impact on crop response. Factors constraining current yields can vary greatly across the HRZ depending on soil type, climate and seasons, highlighting the need for an integrated grower package, targeted specifically to their locality. The approach should draw on and integrate existing knowledge with new knowledge, which assesses the nutrient status of the region, followed by omission plot experiments to generate nutrient response curves. This information can then be used to project yield response to additional rates of nutrient inputs along with the risk probabilities associated with the various outcomes for the economic component of this project.

The biophysical modelling results should feed into an economic analysis to determine the optimal level and mix of fertilisers that could be applied to wheat and canola crops in the HRZ while considering uncertainty of crop response. This analysis will need to consider risky market and seasonal drivers, as well as other important factors such as farmers' budget constraints.

The development of new tools for use by growers and advisors in the HRZ is important. These will help in their understanding of how levels of inputs affect crop potential, economic returns and risks, and feed into their tactical decision-making and profitably boost crop yields across the HRZ.

Acknowledgments

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Simulating grain and grazing yield of diverse wheat genotypes in the HRZ

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Abstract
There is growing interest in the potential to expand cropping into Australia's higher rainfall zone (HRZ). Grain yield and grazing potential from 4 different wheat phenology types sown fortnightly from early March to late June was simulated for 50 years using APSIM at 13 locations across Australia's HRZ. The 4 wheat cultivars represented slow-winter (e.g. Revenue), fast-winter (e.g. Wedgetail), mid-spring (e.g. Gregory) and fast-spring (e.g. Lincoln) maturity types. Potential grazing days were obtained by simulating sheep grazing crops at 25 DSE/ha up until Zadoks stage 30. Optimal sowing dates for each maturity type at each location were matched to the flowering window when the risk of frost and heat stress was lowest. Overall, we found there is significant potential for dual-purpose use of winter wheat cultivars across all regions of Australia's HRZ. Simulated mean wheat yields exceeded 6 t/ha at most locations in the HRZ and were highest (8-10 t/ha mean) in southern Victoria and lowest (5-6 t/ha average) in south-west WA. Highest grazing days were achieved from winter cultivars sown early (March to mid April) which could provide 1700-3000 DSE.days/ha of grazing; this was 2-3 times higher than from grazing spring cultivars (200-800 DSE.days/ha). However, at locations with Mediterranean climates, lower frequency of early sowing opportunities before mid-April (<30% of years) limited the potential utility of winter cultivars. The simulations also emphasised the importance of early sowing, sufficient N supply and sowing densities to maximise grain and grazing potential from crops in the HRZ.

Key words
Dual-purpose, grazing, yield, model, APSIM, cultivar, sowing time

Introduction
There is significant potential and interest to expand cropping into Australia's HRZ where the longer growing season (> 6 months) is thought to offer high grain yield potential, though current yields are limited due to a range of agronomic and edaphic factors (Zhang *et al*. 2006). Dual-purpose crops have been increasingly used in the higher rainfall areas of south-eastern Australia (over 300 000 ha are now sown), where they provide grazing for livestock during winter and later are allowed to regrow to produce grain. Dual-purpose use of crops has the capacity to increase overall profitability and productivity by 25-75% compared to grain only crops (Bell et al. 2014). With the large production and economic benefits possible from dual-purpose crops the scope to expand their use from their traditional areas to new regions of the HRZ requires clarification. This national simulation analysis across Australia's HRZ aimed to quantify the frequency of sowing opportunities, grain yield and grazing potential from a range of wheat phenology types and the influence of sowing date, nitrogen availability and crop density (more detailed analysis can be found in Bell et al. 2015).

Methods
Wheat crop grain yield and grazing was simulated over 50 years at 13 locations distributed across Australia's HRZ using representative soils and long-term climate records from each location. The soil and crop modules from the Agricultural Production System SIMulator (APSIM) were configured in combination with the GRAZPLAN animal models (Holzworth et al. 2014) to simulate potential sheep grazing, and ungrazed crops were used to predict potential grain yield. At all locations a factorial analysis included nine sowing dates simulated at 2-weekly intervals from 8 March to 28 June; 4 different cultivars representing slow-winter (Revenue), fast-winter (Wedgetail), mid-spring (Gregory) and fast-spring (Lincoln) maturity types; 4 levels of N availability (50, 100 and 150 kg N at sowing and unlimited N supplied throughout the season); and 4 plant densities (50, 100, 150, and 200 plants/m^2). For each combination of cultivar by sowing date, risks of frost and heat stress were estimated by categorizing low and high temperature occurrences into mild, medium and severe stress events (Table 1). Using the frequency and intensity of these events that occurred during the critical phenological period around flowering, 'safe' sowing windows for each phenology-type at each location were identified which minimised the risk of heat and frost events. This corresponded to a 18-24 day optimum flowering window when the average frequency of frost stress events (min. temp < 2°C) was less than 2 and average frequency of heat stress events (max temp > 32°C) were less than 1.

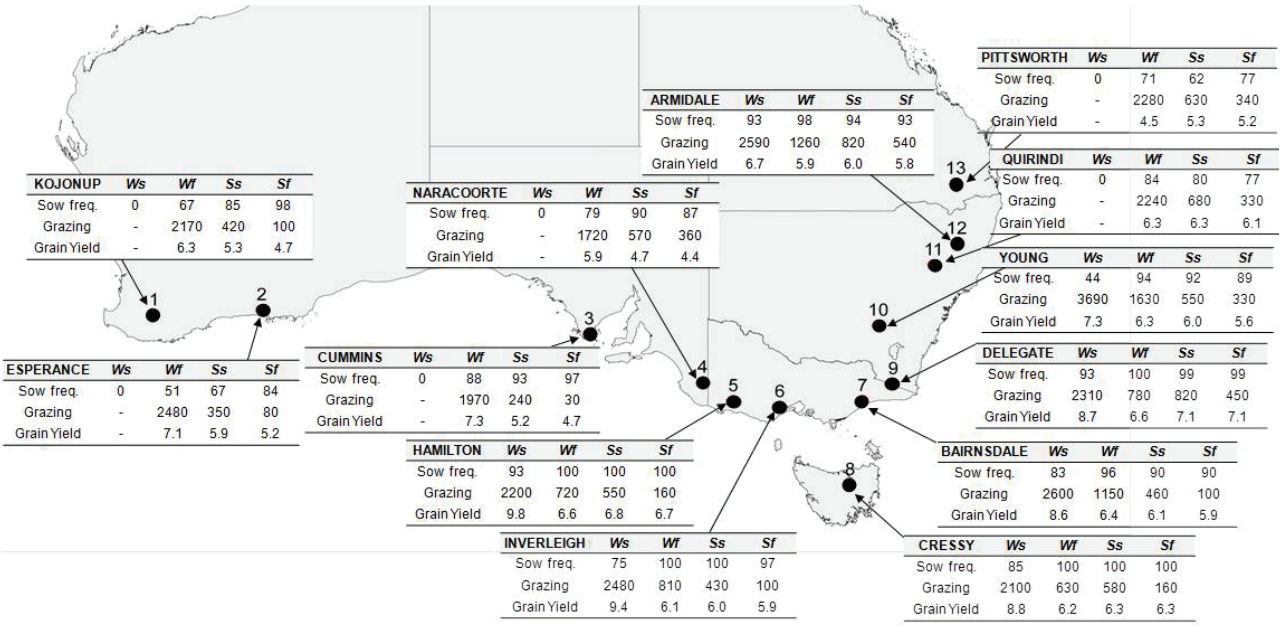
In all simulations, soil water content was set on the 1 February each year at 60% of plant available water with the profile filled from the top (dry at the bottom). To ensure simulated outcomes were produced for all sowing dates and years, the top 30 cm was wet to field capacity on the specified sowing dates to ensure crop establishment; the sowing opportunity for each sowing window was analysed separately (see below). All wheat crops were topdressed with 100 kg N/ha as urea at Zadoks stage 31 and available nitrate was set to a minimum of 50 kg N/ha at sowing. Grazing was simulated using 45 kg wethers (a dry sheep equivalent (DSE) at a stocking rate of 25 head/ha; hence, the predicted DSE.grazing days (DSE.days/ha) from the crop was calculated as the product of the stocking rate and the grazing period (days). Grazing commenced when biomass reached 1500 and 400 kg/ha in winter and spring cultivars, respectively. Sheep were removed when either crop green biomass fell below 400 or 100 kg/ha in winter and spring cultivars, respectively, or when the crop reached simulated Zadoks stage 30 in winter cultivars or 750 ^{o}C.d for Gregory and 600 ^{o}C.d for Lincoln; thermal time was preferred as a predictor of stem elongation in the spring maturity types.

To provide information on the likelihood and riskiness of sowing on specific dates, long-term climate records (1889-2010) for each location were used to analyse the frequency of a sowing opportunity. A sowing opportunity was defined as rainfall exceeding pan evaporation over a 7 day period (Unkovich 2010). Risk of failure to establish crops due to a 'false break' was calculated as the percentage of sowing opportunities in that 'sowing window' (i.e. 2-week period) that were followed by a 4 week period without any further effective rain (rainfall > evaporation over 7 days).

Results

Grain and grazing potential

Opportunities to successfully integrate dual-purpose crops were evident in all regions, but the best and most likely options in terms of varietal selection and sowing date varied. The analysis suggested that on average it is possible to obtain > 1700 DSE grazing days/ha and grain yields of 5.5-8 t/ha from early-sown dual-purpose winter wheat cultivars across locations (Fig. 1). The highest average potential grain yields were 8-10 t/ha from an early-sown slow-winter cultivar in the southern temperate high rainfall zone (i.e. Hamilton, Inverleigh, Bairnsdale, Cressy and Delegate; Fig. 1). In locations with a Mediterranean climate (*e.g.* Kojonup, Esperance and Naracoorte), highest average yields were less (up to 6-8 t/ha) and achieved from the fast-winter cultivar sown early (Fig. 1). On the slopes and tablelands of central and northern NSW (i.e. Young, Quirindi, Armidale), highest average simulated grain yields were ~ 6 t/ha from early-sown winter cultivars (Fig. 1). The average simulated yields were lowest at Pittsworth (Fig. 1). These potential yields agree closely with those obtained in experimental studies across the HRZ.



KOJONUP	Ws	Wf	Ss	Sf
Sow freq.	0	67	85	98
Grazing	-	2170	420	100
Grain Yield	-	6.3	5.3	4.7

ESPERANCE	Ws	Wf	Ss	Sf
Sow freq.	0	51	67	84
Grazing	-	2480	350	80
Grain Yield	-	7.1	5.9	5.2

NARACOORTE	Ws	Wf	Ss	Sf
Sow freq.	0	79	90	87
Grazing	-	1720	570	360
Grain Yield	-	5.9	4.7	4.4

CUMMINS	Ws	Wf	Ss	Sf
Sow freq.	0	88	93	97
Grazing	-	1970	240	30
Grain Yield	-	7.3	5.2	4.7

HAMILTON	Ws	Wf	Ss	Sf
Sow freq.	93	100	100	100
Grazing	2200	720	550	160
Grain Yield	9.8	6.6	6.8	6.7

INVERLEIGH	Ws	Wf	Ss	Sf
Sow freq.	75	100	100	97
Grazing	2480	810	430	100
Grain Yield	9.4	6.1	6.0	5.9

ARMIDALE	Ws	Wf	Ss	Sf
Sow freq.	93	98	94	93
Grazing	2590	1260	820	540
Grain Yield	6.7	5.9	6.0	5.8

PITTSWORTH	Ws	Wf	Ss	Sf
Sow freq.	0	71	62	77
Grazing	-	2280	630	340
Grain Yield	-	4.5	5.3	5.2

QUIRINDI	Ws	Wf	Ss	Sf
Sow freq.	0	84	80	77
Grazing	-	2240	680	330
Grain Yield	-	6.3	6.3	6.1

YOUNG	Ws	Wf	Ss	Sf
Sow freq.	44	94	92	89
Grazing	3690	1630	550	330
Grain Yield	7.3	6.3	6.0	5.6

DELEGATE	Ws	Wf	Ss	Sf
Sow freq.	93	100	99	99
Grazing	2310	780	820	450
Grain Yield	8.7	6.6	7.1	7.1

BAIRNSDALE	Ws	Wf	Ss	Sf
Sow freq.	83	96	90	90
Grazing	2600	1150	460	100
Grain Yield	8.6	6.4	6.1	5.9

CRESSY	Ws	Wf	Ss	Sf
Sow freq.	85	100	100	100
Grazing	2100	630	580	160
Grain Yield	8.8	6.2	6.3	6.3

Figure 1. Simulated potential (N unlimited) grazing days (DSE.days/ha), potential grain yield (t/ha) and probability of a sowing opportunity (% of years) for predicted safe sowing windows for 4 wheat maturity types (Ws - winter slow e.g. Revenue, Wf – winter fast e.g. Wedgetail, Ss – spring slow e.g. Gregory, Sf – spring fast e.g. Lincoln) for 13 locations across Australia's HRZ.

In most environments, highest simulated grain yields came from earliest sown winter cultivars which were higher than those achieved with spring cultivars; the exception was Pittsworth (Fig. 1). In the cool temperate environments typical of the HRZ, the slow-winter cultivar had the highest simulated yield across all sowing dates, although spring cultivars approached similar potential yields from sowing dates after the end of May (Fig. 1).

Winter cultivars provided the most grazing potential with a long period of grazing before the crop reached stem elongation; crops could be grazed for a period of up to 100 days in some environments. In all environments except Naracoorte, more than 2000 DSE.days/ha on average could be achieved from dual-purpose winter wheat sown in March or early April (Fig. 1). By comparison spring cultivars offered significantly less grazing than from the winter cultivars. Nonetheless, in many environments the slower maturing spring cultivar could be grazed for 16-32 days and provide 400-800 DSE.days/ha (Fig. 1). The fast developing spring cultivars offered the least grazing potential, typically less than 400 DSE.days/ha, and limited grazing opportunities in some environments using the grazing rules applied here (e.g. Esperance, Cummins). These predicted forage and grazing yields from dual-purpose crops are consistent with experimental data in regions where this has been measured.

Sowing opportunities

Sowing windows that minimised frost and heat risk during flowering varied amongst locations and maturity types; this typically changed from winter to spring maturity types in early May. In many of the HRZ locations sowing opportunities frequently occurred prior to the safe sowing window for spring wheat cultivars. In the locations with a Mediterranean climate, sowing opportunities before mid April were infrequent (<30%) and risky due to a high chance of false breaks (Table 1). In the southern temperate locations, the likelihood of a sowing opportunity increased and > 30% of years would experience a sowing opportunity in any fortnightly period from mid March (Table 1). In the northern locations, sowing opportunities also occur in 27-50% of years in each fortnight throughout March and April (Table 1). The cumulative probability of a sowing opportunity occurring in the 'safe' sowing window for each maturity type is shown in Figure 1. This shows that for the HRZ locations there are sowing opportunities for a winter cultivars in over 50% of years (> 80% in most locations considered here).

Figure 2 clearly demonstrates the importance of early sowing of dual-purpose wheat crops to maximise their grazing potential across a range of environments. Each week delay in sowing of winter cultivars reduced grazing potential by 200-250 DSE/days/ha. Grazing potential of spring cultivars was less overall and delayed sowing had far less effect on their grazing potential.

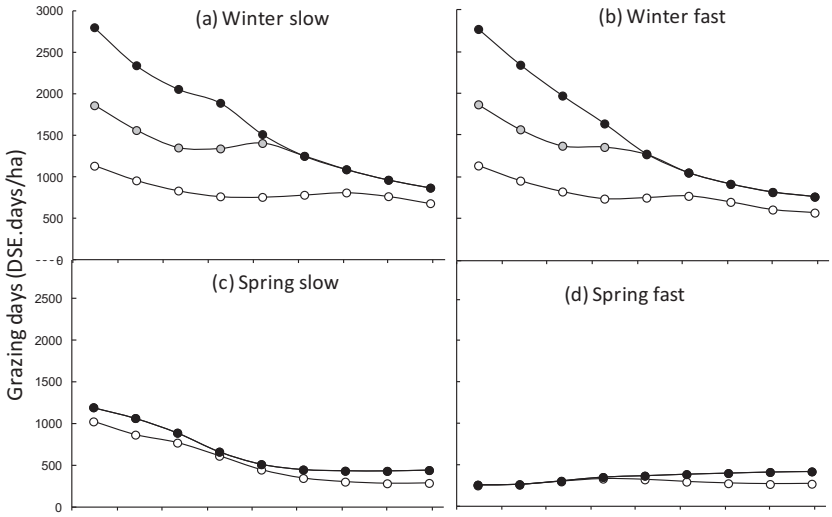
Table 1. Frequency of years (%) with a sowing opportunity (rainfall > pan evaporation over 7 days) and likelihood of a false break (in brackets) with no further effective rain (i.e. rainfall < pan evaporation over 7 days) in the subsequent 4 weeks for each fortnightly period from 1 March to 15 June at 13 locations across Australia's high rainfall zone.

Location	1-15 Mar		15-31 Mar		1-15 Apr		15-30 Apr		1-15 May		15-30 May		1-15 Jun	
Kojonup	5	(67)	8	(70)	19	(35)	21	(15)	48	(2)	79	(0)	88	(0)
Esperance	7	(67)	13	(44)	23	(29)	28	(29)	41	(2)	68	(8)	73	(3)
Cummins	3	(50)	7	(50)	17	(29)	30	(8)	51	(5)	76	(3)	85	(2)
Naracoorte	2	(100)	11	(43)	16	(40)	36	(16)	52	(5)	78	(2)	86	(1)
Hamilton	6	(71)	20	(17)	30	(16)	57	(4)	67	(2)	86	(0)	89	(1)
Inverleigh	17	(57)	25	(29)	38	(20)	52	(10)	60	(3)	83	(1)	84	(1)
Bairnsdale	28	(44)	30	(27)	32	(21)	46	(27)	49	(8)	60	(14)	58	(8)
Cressy	14	(18)	32	(15)	50	(7)	67	(6)	69	(1)	86	(1)	91	(0)
Delegate	32	(36)	41	(30)	37	(22)	51	(24)	50	(2)	69	(5)	76	(6)
Young	22	(9)	30	(10)	34	(7)	48	(3)	60	(3)	77	(2)	84	(0)
Quirindi	27	(36)	29	(43)	30	(36)	31	(24)	34	(14)	60	(10)	63	(8)
Armidale	50	(33)	35	(33)	48	(29)	39	(25)	49	(12)	57	(9)	72	(5)

N supply effects on grazing potential

Across all locations crop N supply was found to be a key factor influencing the grazing potential of dual purpose wheat crops. Figure 2 shows an example of the simulated response of the 4 different phenology-types to available N at sowing at Hamilton, Victoria; similar responses are found at other locations. N availability had the largest effect on grazing potential of early sown winter wheat (Fig. 2). For example, on average a winter wheat cultivar sown in March could produce > 2000 DSE.days/ha when 150 kg N/ha was available at sowing, while this was reduced to 1300-1700 and 600-1200 DSE.days/ha when only 100 and 50 kg N/ha was available at sowing, respectively. The potential for greater N application to maximise early biomass production and therefore grazing from early-sown winter maturity types was observed across most locations. In later sowing dates and in spring cultivars the influence of N availability at sowing on grazing was less, with little or no increase in grazing obtained beyond 100 kg of N/ha at sowing.

Figure 2. Effect of sowing date and available nitrogen at sowing (hollow- 50kg N/ha; grey- 100kg N/ha; black- 150kg N/ha) on grazing days (DSE.days/ha) from 4 wheat maturity types, winter-slow (i.e. Revenue) (a), winter-fast (i.e. EGA Wedgetail)(b), spring-slow (i.e. Gregory) (c) and (d) spring-fast (i.e. Lincoln) at Hamilton.



Conclusions

Based on the assumptions of this simulation analysis, we find significant opportunities to expand the use of wheat crops for both dual-purpose of grazing and grain production across Australia's HRZ including new environments such as south-west Western Australia and parts of the northern tablelands and slopes. Frequent early sowing opportunities and longer growing seasons in many of these areas make them suitable for longer season winter cultivars, which can provide large amounts of grazing for livestock and higher grain yields than traditional spring cultivars used in the lower rainfall systems. Nonetheless, the use of shorter winter cultivars and longer season spring cultivars could also open up new environments where dual-purpose use of crops can be practiced. Spring cultivars provided significantly less grazing opportunities (typically < 600 DSE grazing days/ha) and had lower yield potential by 1-3 t/ha compared to the early sown winter cultivars. Though the earlier-sown winter cultivars have a clear advantage in higher grazing potential (usually 2-3 times), the combined grazing and grain yield potential for mid-spring types in most areas are significant.

Acknowledgements

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The response of hybrid and open-pollinated canola to the environment in southern Australia

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Abstract
Realising high yield potential of hybrid canola is strongly dependent on the environment and the profitability of hybrid technology must be assessed against open pollinated (OP) canola. This study compared the yield and gross margins of hybrid and OP canola across a wide range of environments in Western Australia (WA), and in the National Variety Trial network (NVT) across southern Australia. Hybrid canola had yield advantages over OPs in favourable environments where rainfall was high (>300 mm) and the growing season was long. However, in areas of low rainfall where yield potential was low (< 260 mm), hybrids showed little yield advantages over OPs. The gross margin analysis suggested that hybrid triazine tolerant, conventional and Roundup Ready canola was profitable in the medium and high yielding environments, but not profitable in the low yielding environments because the cost associated with seed outweighed any small yield benefit.

Key words
Hybrid, open-pollinated, gross margin.

Introduction

Canola production in Australia is moving into lower rainfall areas from its initial high rainfall zone (HRZ) heartland, and playing different roles, from cash crop in the HRZ to break crop in the low rainfall area, depending on yield potential and farming system need. Current canola cultivars offer a range of options to accommodate the needs of growers across the rainfall zones using hybrid (HB) and open pollinated (OP) cultivars with four of herbicide tolerances (HT) groups (triazine tolerant: TT; Roundup Ready: RR; imidazoline tolerant or more commonly used Clearfield: CL, and conventional: CV). OP TT canola seed is cheap (ca. $2/ha), offers robust weed control and has been widely adopted, despite the acknowledged yield penalty associated with the technology. Conversely, hybrid canola is more vigorous and weed-competitive, and can yield up to 20% more than OP cultivars in Australia and Canada (Brandt et al., 2007; Kirkegaard et al., 2012), but it is more expensive to grow as hybrid seed costs approximately $27-34/kg. Recently, canola breeding has gradually shifted from OP to hybrids because canola breeders value the income stream presented by hybrid production as seed cannot be retained by farmers. One of the important questions faced by growers is whether they should grow hybrid or OP canola, given the yield-cost trade-off and this is likely to depend upon yield potential of specific sites according to rainfall and growing season length. While hybrid canola might provide opportunities to achieve higher yield, is it more profitable at a given environment? This paper seeks to answer these questions and provide growers with guidelines to select the right varieties. It also serves to demonstrate to seed suppliers and breeders which varieties are likely to be relevant in different regions in the longer term and which direction breeding effort for canola should be focused.

Method and materials

A total of five field experiments using 19-20 canola varieties and two nitrogen (N) rates (0 and high, as appropriate for the rainfall zone) were conducted in the low (Merredin, 2014), medium (Cunderdin, 2013 and 2014), and high (Kojonup, 2013 and 2014) rainfall areas of Western Australia. Current cultivars were used, balanced by heterosis (OP and hybrid), herbicide group (TT, RR, CV and CL) and phenology as much as possible. Experiments were laid-out in a split-plot design with herbicide group as main plots to facilitate the contrasting herbicide treatments, and replicated three times at each location. The high N rate treatment increased with rainfall zone, from 80 kg N/ha at Merredin, 100 kg N/ha at Cunderdin, and 150-175 kg N/ha in Kojonup. At seeding, 20 kg N/ha was drilled as a base application, 50% of the remaining N was applied

at the six leaf stage and the other 50% at bud visible stage as urea. The seeding rates were set to achieve 40 plants m-2 based on seed weight and a *priori* germination rates. For each herbicide group, the corresponding herbicides were sprayed to control weeds. The plot size was 20 m by 1.54 m. The whole plot was harvested using a plot harvester and 1 kg of seed sample from each plot was collected to analyse oil, protein and moisture content using a calibrated FOSS Infratec. Yield was reported at 8% moisture and 42% oil content. In addition to these experiments, the NVT data from experiments in Western Australia, Victoria, New South Wales, and South Australia from 2010 to 2014 were provided by the Australian Crop Accreditation System Limited (ACAS). To minimize the effect of imbalance, only varieties tested at > 20 locations were included in the analysis. Finlay-Wilkinson (1963) analysis was used to quantify responsiveness to environment using the 2 N treatment means for each of the 5 trials to provide a total of 10 environment means from Merredin (2014), Cunderdin (2013, 1014) and Kojonup (2013, 1014) in regressions of varieties nested within heterosis and/or herbicide groups. The same Finlay-Wilkinson (1963) regression was performed on the NVT data. Residual plots were generated in both regression and ANOVA to detect errors and check for common, independent error variance. In order to estimate the gross margin of hybrid and OP systems, the yield of hybrid and OP canola was derived from the Finlay-Wilkinson linear regression equations from the NVT data. The N fertiliser input cost varied with yield while the other nutrients cost was set at $34/ha. The assumption was that 50 kg N/ha are required to produce 1 ton of canola grain. The cost of input for different herbicide systems and grain price for canola was based on current agronomic consultants' estimation. The grain price was set at $523 for CL, TT, and CV canola and $509 for RR canola. In order to make sure that breeders can recover their investment in OP canola varieties, we assumed $5/ton of end point royalty for OP canola and subtracted the end point royalty from the revenue for all OP canola.

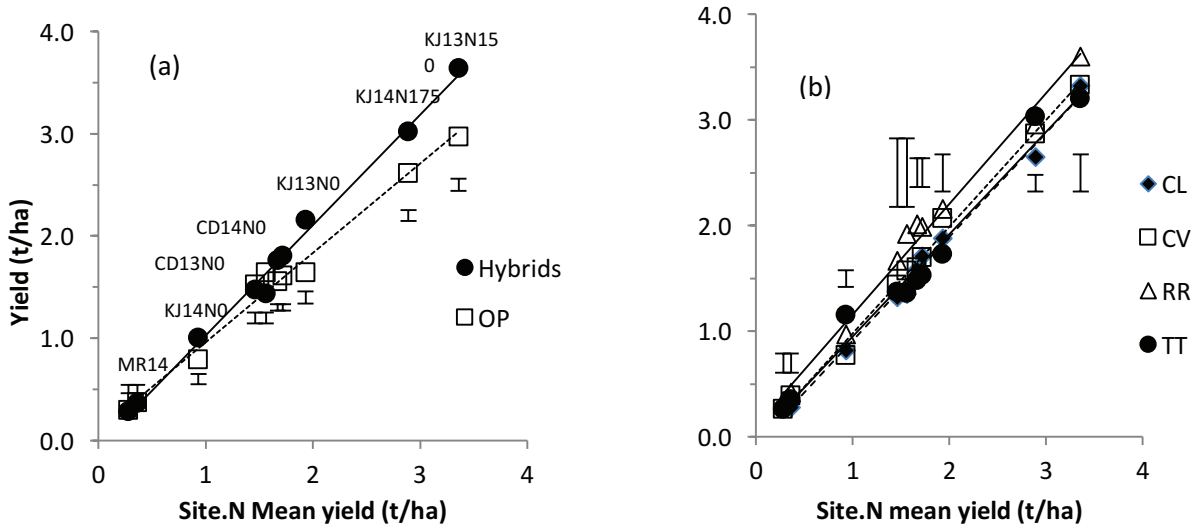

Fig. 1 The response of (a) hybrid and open pollinated (OP) canola, and (b) four herbicide systems (Clearfield: CL, conventional: CV, Roundup Ready: RR, and triazine tolerant: TT) to yield potential represented by the site.N mean yield at five site and year combinations in 2013 and 2014. The letters followed by two digits and N treatment represent the site (Kojonup: KJ, Cunderdin; CD, Merredin: MR), year and nitrogen treatment.

Results

A Finlay- Wilkinson (1963) approach of regressing hybrid and OP means against each site by year N treatment mean (e.g. low and high N means per site year) was very effective, capturing 96% of variance. The large slope differences were between hybrid (1.087±0.0018) and OP (0.883±0.03) canola (Fig.1a), with only minor cultivar differences within heterosis groups. This resulted in a fan-shaped response to site yield potential (Fig. 1a), where both heterosis groups emerge from a common yield at low yielding sites (0.32 for hybrid s and 0.33 for OPs at Merredin), and then separate as site mean yield > 1 t/ha. In contrast to the heterosis groups, there were no slope differences between the 4 herbicide tolerance groups, indicated by the parallel lines in Fig. 1b. However, RR canola had a consistent 0.2 t/ha ($P < 0.05$) yield advantage over the others (CL, CV and TT canola), captured by intercept differences in the regression.

Finlay- Wilkinson (1963) analysis was also very effective for showing national differences in canola responsiveness, capturing 94.4% of variance of NVT trials. When the data from 4 HT groups in WA, NSW,

Vic and SA were pooled, the accumulated analysis of variance showed that the heterosis group and its interaction with site and HT groups had significant effects on yield and that no interaction was observed between the state, HT and heterosis groups. Because the interaction between heterosis and HT groups was significant, we subdivided the dataset into TT, RR, CL, and CV groups for the Finlay-Wilkinson analysis. For TT and RR canola, hybrids had significantly ($P < 0.01$) greater slopes than their OPs (Fig. 2a, b). The slopes for hybrid and OP CL and for hybrid and OP CV were not significantly different (Fig. 2c, d). Both hybrid TT and RR canola had similar yields to OP canola when the site mean yield was low (<0.7 t/ha). However, as the site mean yield increased, the advantage of hybrid canola become more apparent and the responses of hybrids to environment were greater than OPs for TT and RR canola (Fig.2a, b). Although the responsive slopes were similar, hybrid CV produced higher yields than OP CV because of a significantly greater intercept difference (0.28 t/ha) (Fig. 4d). However, there was no significant difference in yield between hybrid and OP CL canola.

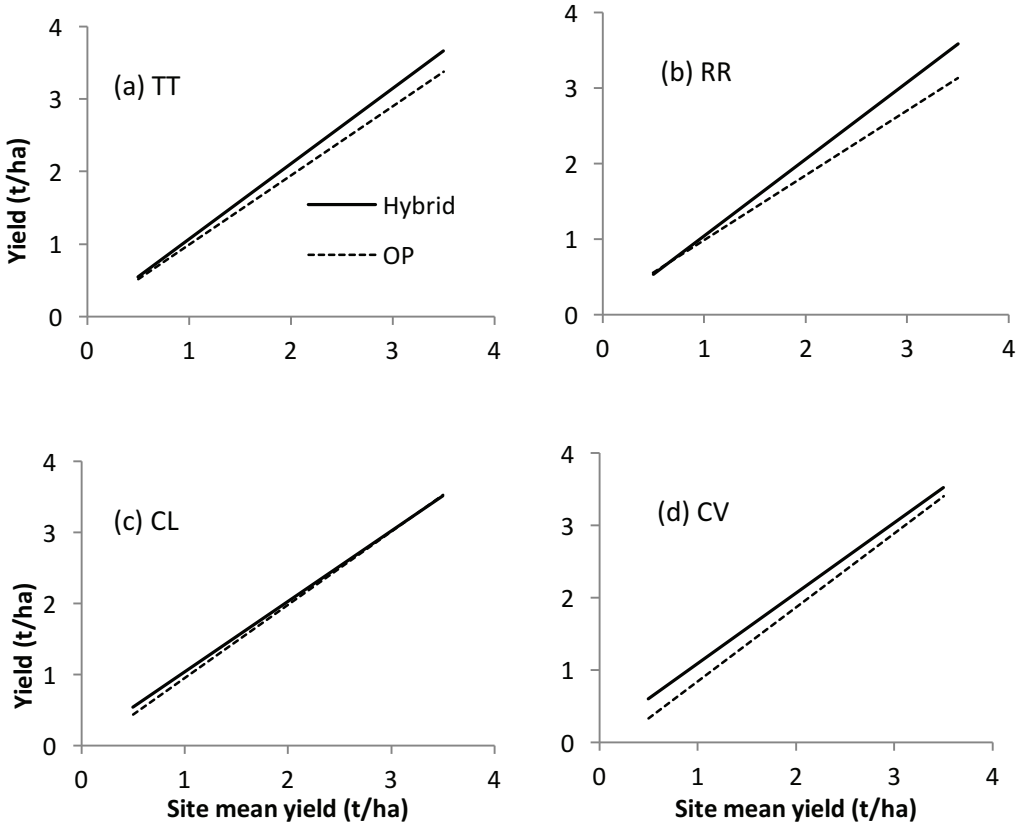

Fig. 2 Responses of hybrid and OP (a) TT, (b) RR, (c) CL and (d) CV canola to the environment in Western Australia, Victoria, New South Wales and South Australia from 2010 to 2014.

Given the fan-shaped yield responses of OP and hybrid canola, gross margins were strongly linked to yield potential: hybrid canola was profitable only when the gains from higher yield outweighed the additional seed cost. Differences in costs, value and yield responsiveness of OP and hybrid canola among the 4 herbicide groups lead to different yield-gross margin relationships (Fig. 3). In RR canola, the break-even yield between OP and hybrid was 0.7 t/ha (Fig. 3a) because OP RR canola is considerably less yield responsive than H hybrid RR canola. Conversely, the break-even mean yield was 1.3 t/ha for hybrid versus OP TT canola (Fig. 3a). For CL canola, hybrids were less profitable than OP CL canola because of similar yields and high cost associated with HYBRID seeds. Compared with OP CV, it was more profitable for hybrid (Fig. 3a) because hybrid CV always produced higher yield than OP CV (Fig. 2d). Given the prevalence of OP TT in Australian production, it is useful to set this as a standard in comparisons (Fig. 3b). Compared with OP TT canola, hybrid RR and hybrid CV become more profitable only when yield is greater than 2.4 t/ha and 1.0 t/ha (Fig. 3b), respectively, while hybrid CL is less profitable throughout the experimental yield range because of the most expensive herbicide cost among the 4 systems.

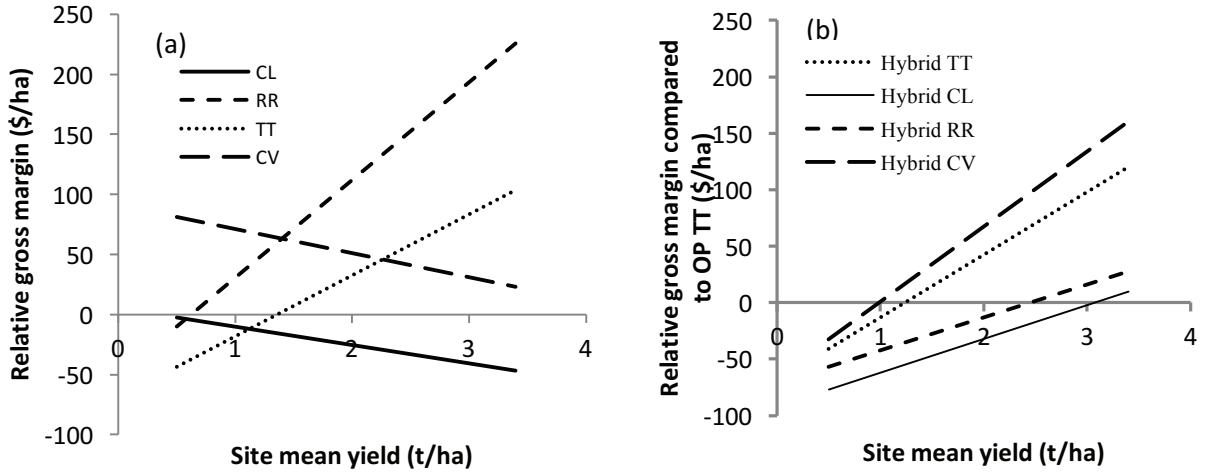

Fig. 3 The gross margin (GM) analysis of (a) hybrid canola for four herbicide tolerance groups (Clearfield: CL, conventional: CV, Triazine tolerant: TT, and Roundup Ready: RR) compared their open-pollinated counterparts and (b) hybrid canola compared to open-pollinated TT canola.

Discussion

Our study showed that the relative yield performance and profitability of hybrids over OPs strongly depends on site potential yields associated with growing season rainfall in Australia and the herbicide groups considered. This is in contrast to the consistently higher yield advantage and profitability of hybrids over OPs reported in Canada (Brandt et al., 2007). The greater yield and gross margin advantage of hybrids over OPs makes hybrids the best option in favourable environments where rainfall is relatively high (> 300 mm) and the growing season is relatively long. However, in areas of low rainfall coupled with high temperatures during the seed filling period, hybrids showed little yield advantages over OPs. The gross margin analysis suggests that hybrid RR and TT canola were profitable in the medium and high yielding environments where potential yield was high. However, they were not profitable in the low yielding environments because the cost associated with seeds outweighed the small yield benefit. This probably explains why around 80% of canola grown in Australia is still OP TT canola. This leads us to conclude that canola breeding in Australia must take into account this fact. The high potential yield and profitability of hybrid canola in favourable high rainfall areas will require canola breeding companies to use the advantage of heterosis to breed hybrid canola. However, the low profitability of hybrids in the low rainfall areas suggests there will be little market for hybrids and requires them to continue to embrace OP TT canola. The departure from breeding OP canola raises the necessity to restore the end point royalty system that allows breeders to recoup their investment. The end point royalty system has been very successful for wheat breeding. Whether an end point royalty system will work in canola is still in question because a much smaller area of canola (20% of wheat area) is grown. Furthermore, farmers can purchase a small amount of OP canola seed and grow them in nursery to produce seeds for next few seasons without need to purchase seeds every year. This makes the end point royalty system much more attractive to breeding companies.

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Commercial wheat varieties are broadly adapted to time of sowing in Australia

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Abstract
Here we explore whether cultivar choice for spring wheat (*Triticum aestivum*) should follow the established doctrine of sowing fast maturing varieties late, and slow maturing varieties early. We quantify the extent of genotype (G) * environment (E) * management (M) available to farmers using commercially released varieties. Nineteen cultivars of spring wheat (*Triticum aestivum*) were sown at 3 times of sowing (early, conventional and late) at 13 sites across Australia 2011 and 2012. For grain yield, there was little difference for a given sowing data, season and location between commercial varieties, where cultivar yields ranged from 2.74 t/ha to 3.08 t/ha. Site yields ranged from 0.8t/ha to 4.5 t/ha, while time of sowing effects ranged from 3.27 to 2.41. The two and three way interactions were of comparatively minor importance, and in general, changing cultivar could not overcome the effect of a late time of sowing. One cultivar (cv Wylkatchem), regularly yielded as well as the other best performing cultivar, regardless of time of sowing or location. The three way interaction between cultivar, environment and management for yield was small. Furthermore, cluster analysis suggest the Australian grain growing regions could be clustered into two broad groups, northern and southern and the stresses imposed on a crop are a greater discriminator of environment than location per se. Based on these analyses, commercially available varieties are broadly adapted to the range of environments across the Australian grain growing region. There was no evidence to suggest farmers could exploit a cultivar by management interaction and should therefore simply choose the best performing cultivar for their region.

Introduction

In Australian farming systems, farmers are often advised to alter their chosen wheat cultivar, based on the time of sowing. Furthermore, the recommendations for particular cultivars changes from region to region and state to state. For spring wheat cultivars, the basis for cultivar recommendation can be distilled into a simple message of "sow a fast maturing spring wheat cultivar late, and sow a slow maturing spring wheat cultivar early". The objective here is to ensure the wheat crop flowers at an optimum time, after the last frosts, but before the onset of terminal drought and heat stress at the end of the season. Such long established principles, described by Passioura and Angus (2010) are useful for developing management strategies for farmers. However, these principals must be contextualised in terms of issues raised by Chenu et al (2010), where the end of the season and season length is often difficult to define until after the fact. This difficulty arises because late season rains are most unpredictable and variable. The implication is that depending on soil type, and stored soil water, the timing and duration of terminal drought is difficult to define for a region because it varies from one year to the next. An inability to precisely define season length may complicate the decision surrounding cultivar choice and time of sowing of spring wheats, particularly if the frost risk is low, or unimportant.

Therefore, we explore how the time of sowing interacts with cultivar at 13 sites sown across Australia in influencing crop yield. We utilise these data to determine how many groups of environments exist across Australia, and whether the cultivar should be altered with a change in the time of sowing at each location

Methods

A total of 13 trials were established in Western Australia, South Australia, New South Wales, Victoria and Queensland using 19 cultivars of spring wheat (Table 1). Cultivars were selected in consultation with breeders, that represented fast (eg Axe), moderate (eg Yitpi) and slow (eg Bolac) maturity. Not all cultivars were sown at each site, as breeders recommended particular cultivars for particular locations. The check cultivars Janz, Gladius and Gregory were sown at each site. Cultivars were then planted at 3 times of sowing, defined as early (time of sowing 1, TOS 1, 29 April – 25 May), conventional (TOS 2, 21 May to 15 June) and late (TOS 3, 20 June to 5 July). Trials were established with sufficient levels of N P and K. Crop

yields were measured estimated by hand cutting 4 0.25m^2 quadrats in each plot. The trial was arranged as an unbalanced incomplete split plot design, with two blocks (replicates) at each location. The main plots are time of sowing and the split plots are cultivar, which are incompletely replicated across and within sowing times. This means a cultivar may be replicated 9 times (3 reps of 3 times of sowing), 6 times (2 reps of 3 times of sowing) or 3 times (1 rep of 3 times of sowing).

Table 1 Varieties and their relative rates of maturity

	Maturity		
Fast	**Fast-Moderate**	**Moderate**	**Slow**
Axe	Crusader	Derrimut	Wylie
Westonia	Carnamah	Correll	Endure
Lincoln	Gladius	Magenta	Bolac
Livingston	Yitpi	Lang	
Wyalkatchem	Scout	Gregory	
	Janz		

Table 2 The times of sowing and mean yield for each time of sowing within a site for the 13 experiments

Site	**Time of sowing 1**	**Yield**	**Time of sowing 2**	**Yield**	**Time of sowing 3**	**Yield**
Bungunya	10/05/2012	3.3	22/05/2012	2.9	23/06/2012	2.4
Nangwee	17/05/2012	3.6	31/05/2012	3.5	23/06/2012	3.8
Spring Ridge	09/05/2011	3.7	06/06/2011	5.2	23/06/2011	5.1
Temora	05/05/2011	4.1	26/05/2011	3.8	20/06/2011	3.1
Walpeup	29/04/2011	3.3	31/05/2011	2.5	01/07/2011	2.3
Turretfield	30/05/2012	2.6	15/06/2012	2.0	05/07/2012	1.6
Turretfield	18/05/2011	5.2	08/06/2011	3.6	28/06/2011	3.6
Minnipa	25/05/2012	2.1	08/06/2012	1.6	25/06/2012	1.5
Minnipa	13/05/2011	3.8	27/05/2011	3.6	24/06/2011	2.1
Corrigin	02/05/2012	2.0	21/05/2012	1.6	21/06/2012	1.1
Corrgin	30/04/2011	4.2	24/05/2011	3.8	21/06/2011	3.3
Eradu	02/5/2012	0.9	21/05/2012	0.9	21/06/2012	0.7
Eradu	29/04/2011	2.6	24/05/2011	2.4	23/06/2011	1.2

Statistical Analysis

Yield data were analysed using a linear mixed effects model. In the random model, site, time of sowing and cultivar, block within site and time of sowing within block within site were included. The predicted values for cultivar, site and time of sowing were then subjected to a cluster analysis to determine which varieties clustered together across sites and times of sowing. A second cluster analysis was conducted to determine how many environments were evident, given this suite of varieties, across the Australian wheat grain growing region.

Results

Site was the dominant effect on grain yield. The lowest yields were recorded at Eradu in 2012 (0.8 t/ha), Corrigin in 2012 (1.6 t/ha) and Minnipa in 2012 (1.8 t/ha). In contrast, high yields were recorded at Spring Ridge in 2011 (4.7t/ha) and Turretfield (4.1 t/ha). On average, yields declined from 3.2 t/ha to 2.5 t/ha from the first time of sowing to the third time of sowing. However, the response to time of sowing did vary between sites (table 2). The yield variation between individual cultivars was comparatively small, relative to site and time of sowing. The best performing cultivar was Wyalkatchem at 3.0 t/ha. Endure, Lang, and Yitpi all yielded 2.8 t/ha.

When the statistical predictions for cultivar performance across each time of sowing were calculated at each site, the yield predictions suggest the highest yielding cultivar for a particular site at time of sowing 1 or time of sowing 2, would at least equal the yield of the highest yielding cultivar at time of sowing 3. While the actual cultivar rank may change, the standard errors of the effects generated from the third order interaction of site by time of sowing by cultivar were too great to differentiate between varieties with yield differences of 5% or less. An example of this effect is presented here for Eradu in 2011 and 2012, where yields ranged from 0.8t/ha to 3.8 t/ha in 2011 and from 0.5 t/ha to 1.3 t/ha in 2012 (Figure 1). At Eradu, the cultivar Wyalkatchem always yielded best, or equal best, for all three times of sowing. As a result, farmers should simply grow the best performing cultivar, regardless of time of sowing, unless they are concerned about frost risk. A similar outcome occurred at the other 12 sites.

Cluster groups of cultivars

The cluster analysis of cultivars, using varieties and their yields at each site and time of sowing is presented in Figure 2. The dendrogram illustrates how Wyalkatchem does not group with any other cultivar. Gregory and Gladius also grouped separately. 11 cultivars aggregated into one group which can broadly be considered fast to moderately fast. Of the 5 varieties (Crusader, Correll, Endure, Lang, Yitpi) that classify into the second group, only 3 (Endure, Lang and Correll) were described as slow maturing. The others were again grouped into the moderate category (Table 1). Therefore cultivars did not clearly discriminate by maturity type based on their yield performance.

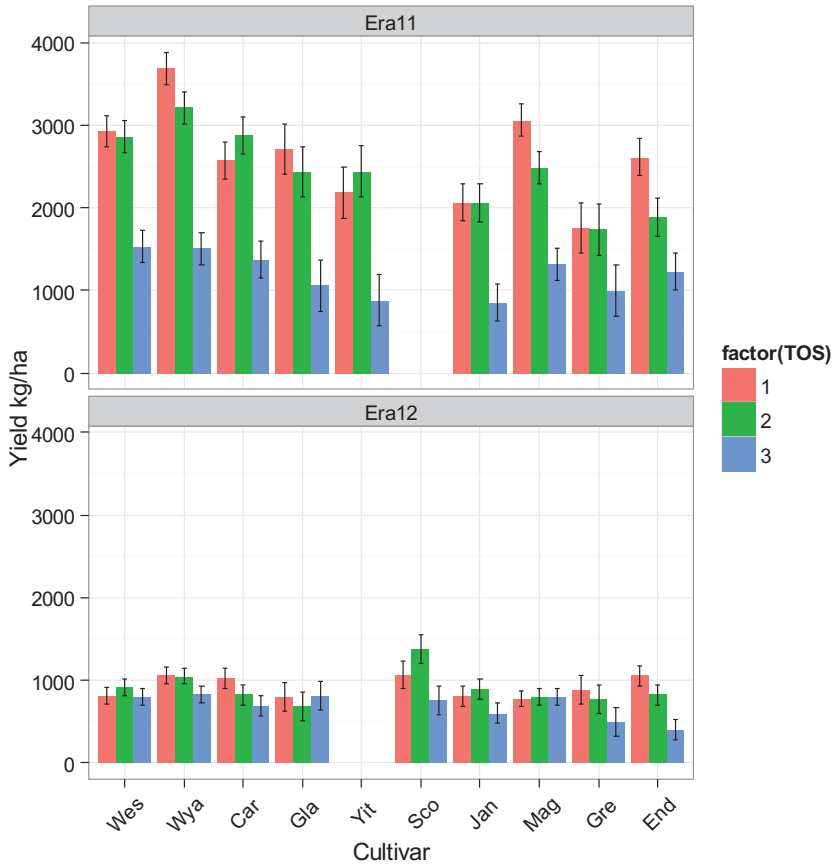

Figure 1. Yields for 10 cultivars at Eradu (Western Australia) in 2011 and 2012 at each time of sowing. Error bars denote the standard error of the mean.

Cluster Groups of Environments

Sites and times of sowing generally clustered into two broad groups. For the group on the right side of the dendrogram (red box), Eradu (WA), Corrigin (WA), Minnipa (SA), Turretfield (SA) and Walpeup (Vic) aggregated together, regardless of time of sowing. However, there were some exceptions. Crops from the third time of sowing at Bungunya in 2012 also appeared in this group. In addition, crops from Corrigin and Turretfield grown in 2011 at all times of sowing appeared in left hand group. Crops sown at time of sowing 1 and 2 from Minnipa and time of sowing 1 Walpeup in 2011 also appeared in the right hand side group. The

right hand side group was otherwise populated by sites from Nangwee, Bungunya, Temora and SpringRidge. Therefore, based on the performance of commercial varieties, we could conceivably split the Australian grain growing environment into two groups, north and south. Furthermore, in favourable southern seasons, this aggregation could be simplified further, and the country classified into 1 group. Crops tend to aggregate into the second group when stressed and lower yielding. We argue that the extent of stress is a greater discriminate of environment than location, as the southern locations change groups when conditions are favourable.

Conclusion

Commercially available wheat cultivars are broadly adapted to the Australian environment. Frost notwithstanding, there is little evidence to suggest farmers should alter cultivar choice based around time of sowing, and they should simply grow the best performing cultivar for that region. While this is counter intuitive, it occurs because of the broad adaptation of Australian commercial spring wheats. This broad adaptation means that the same or similar varieties can be considered for much of the Australian continent.

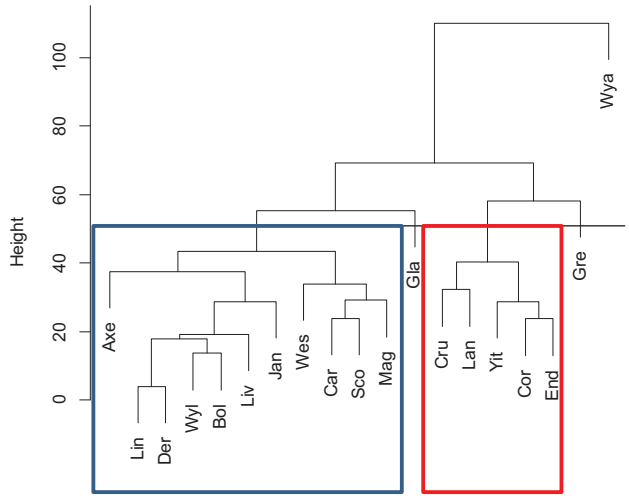

Figure 2. Dendrogram grouping of cultivar performance (denoted by the red and blue boxes cut at a height of 50) based on yield across sites and times of sowing

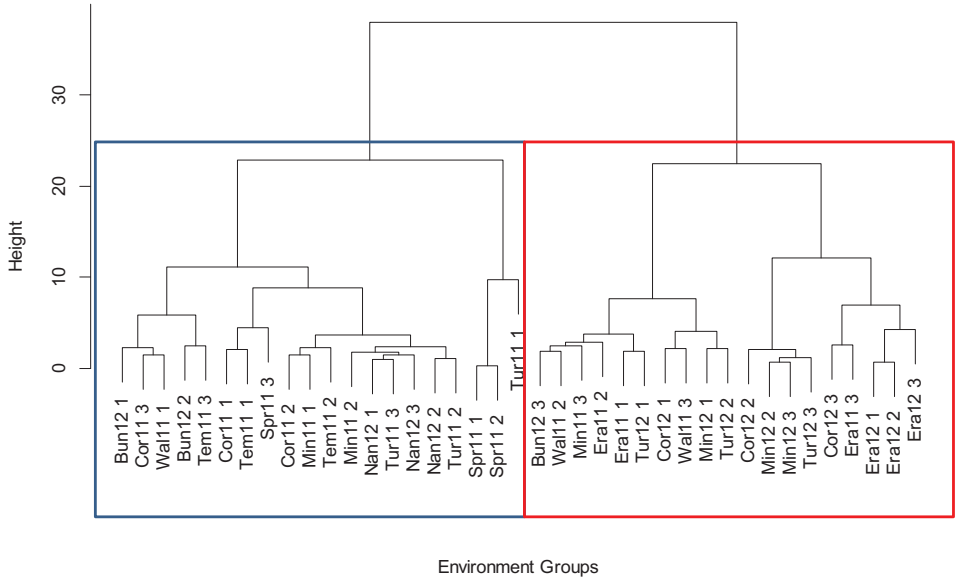

Figure 3. Dendrogram grouping (identified by the red and blue boxes, cut at a height of 25) for time of sowing and site, based on cultivar performance.

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Pushing the limit for water-use efficiency in early-sown canola

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Abstract
Early sowing of canola (late April to early May) in eastern Australia is known to increase canola yield potential and water-use efficiency, but the opportunity to capture further benefits from earlier April sowing is uncertain. The risk of frost or excessive early biomass production are concerns, especially for modern vigorous hybrid varieties, but could be managed by selecting varieties with appropriate phenology and managing canopy development. We conducted 6 experiments in eastern Australia during 2014 to investigate the yield and water-use efficiency of modern canola cultivars sown from early April. Sowing early (April 1 to 15) maximised the yield at all sites, except Condobolin where frost and water stress reduced yield of early-sown crops. Variety choice was critical for early-April sowing - slower developing varieties had highest yield from early sowing, while faster developing varieties developed pods in mid-winter which suffered frost damage and could not compensate where spring drought was severe. The transpiration efficiency of the highest yielding, early-sown varieties equalled or exceeded the previously established benchmark of 15 kg/ha/mm for canola. These results suggest that early April sowing of canola may be feasible to boost yield and water use efficiency in low-medium rainfall zones with correct variety choice and suitable management.

Key words: water use, early vigour, drought, water stress, deep roots

Introduction
Canola is the third most important grain crop in Australia worth around $2.7Bill in 2012/13 and is also the most widely grown and important break crop for cereal-based farming systems. The importance of early-sowing to maximise yield potential and water-use efficiency in canola has been known for some time, with yield loss of around 5% per week delay in sowing from the recommended late-April sowing (Robertson and Kirkegaard 2005; Lisson et al., 2007). Changing seasonal conditions and improved agronomy have created interest in the feasibility to move canola sowing into early April to capitalise on higher yield potential. However as well as the potential for increased frost risk if flowering time is not well matched to early-sowing, there is also concern regarding the risk of excessive early water use by high vigour hybrids causing increased risk of water stress during flowering and pod-fill. Early April sowing is advised for the higher rainfall zones with later-maturing winter-type canola (Christy et al., 2013) and for grazed canola (Kirkegaard et al., 2012), but there is little commercial or experimental experience of spring-type canola sown in early April in low-medium rainfall zones. From a physiological point of view, the water-use efficiency of early-sown canola could be increased through (i) rapid soil coverage to reduce evaporative loss (E) and increase transpiration (T), (ii) more efficient T during vegetative growth due to cooler conditions and lower vapour pressure deficit (VPD), (iii) reduced heat and water stress during reproductive stages in spring and (iv) increased access to deep stored water due to longer vegetative stage and deeper rooting (Robertson and Kirkegaard 2005). We report outcomes of a series of experiments in eastern Australia during 2014 investigating the yield and water-use efficiency of canola crops sown from early April.

Methods
A series of replicated canola variety x sowing time experiments were conducted at 6 sites across eastern Australia in 2014 (Breeza, Trangie, Condobolin, Greenethorpe, Ganmain, Junee). The experiments comprised 3 or 4 replicates arranged as blocks with individual plot size 10m x 2m. The 7 varieties included a range of current modern spring hybrid and triazine-tolerant (TT) varieties (Hyola575CL, 45Y88CL, 44Y87CL, 44Y84CL, 43C80CL, Hyola559TT, ATR-GEM). Only Hyola575CL and 44Y87CL were grown at all sites, with 3-5 varieties representing commonly grown commercial varieties selected for each site. The sowing date treatments spanned the window from April 1 to May 23 and usually consisted of 4 sowing dates around 14 days apart. All trials were sown into moisture so germination commenced at sowing rather than on a subsequent rainfall. At each site, the canola was sown to establish a target population of 45 plants m^{-2} based on seed size and germination percentage. At some sites a lower plant population (15 plants m^{-2}) was included, and although the interactions with density are not considered here, yield data for each site are presented for the highest yielding plant population. Weeds were managed at each site using recommended

herbicides, and crop nutrition was managed using pre-sowing soil tests and top-dressing to guide fertiliser management to avoid nutritional constraints to crop growth. Crop measurements included established plant population, flowering date, biomass at 50% flowering, seed yield and yield components. Biomass, yield and yield components were measured from 1m^2 quadrat cuts (2 x 0.5 m^2) cut at ground level at 50% seed colour change on the main stem. Seed yield was also measured from machine harvested strips taken from each plot, however difficulty in harvesting mechanically at the optimum time to avoid shattering loss at some sites meant that the yield data from hand quadrat cuts was used for consistency.

Water use efficiency was estimated as [yield (kg/ha)/ET (mm)], where ET = rainfall from sowing to harvest plus the stored soil water used. Measurements of soil water use were from gravimetric soil water measurements on soil cores (to 1.8m) taken pre-sowing and post-harvest at the sites, or from calibrated neutron moisture probes. Where soil water was not measured (Condobolin, Trangie, Ganmain), soil water use was estimated assuming 30% of summer fallow rainfall (December to March) was available at sowing, and that no plant available water remained at harvest due to the dry spring finish at the sites. Thus 30% of January to March rainfall was assumed to be used by the crops in addition to the in-crop rainfall to estimate ET. Frontiers for transpiration efficiency were considered using different estimated evaporative losses.

Results

Seasonal conditions in 2014

The 2014 season at all sites was characterised by average to above average fallow (Jan – March) rainfall (100 to 200 mm) which facilitated early April sowing into reasonable levels of stored water (see Table 1). The good early start was followed by average autumn and winter rainfall, but the spring was very dry at all sites, and the crops relied on stored soil water during the flowering and pod-filling period. Although in-crop rainfall ranged from 177 (Trangie) to 396 mm (Greenethorpe), very little of this occurred after August. The autumn and early winter temperatures were above average which accelerated the development of some varieties especially from early sowing. At Condobolin, Ganmain, Junee frosts were severe during mid-July to early August which affected varieties that were at the susceptible water-filled pod stage at that time. No significant frost damage occurred at Greenethorpe and no observations are available for Breeza or Trangie.

Table 1. Components of WUE estimates including fallow and seasonal rainfall, change in soil water and maximum canola yield recorded at each site in 2014

	Sites in 2014					
	Greenethorpe	Breeza	Junee	Ganmain	Trangie	Condobolin
Rain (Jan-Mar) (mm)	46[a]	100[a]	90[a]	100	202	180
In-crop Rain (mm)	396	184	229	270	177	180
Total ET (mm)	442	284	280	230	178	174
Maximum yield (t ha^{-1})	6.01 (S1)[d]	3.50 (S1)	2.69 (S1)	3.14 (S2)	2.22 (S2)	1.22 (S3)
WUE (Yield/ET)[b]	13.6	12.3	8.4	10.5	9.3	5.1
TE (Yield/(ET - 60)[c]	15.7	15.6	10.5	13.1	12.5	7.0

[a] Measured change in soil water (sowing to harvest) shown was used in ET calculation rather than 30% Jan-Mar rainfall
[b] WUE=Water Use Efficiency [Yield/ET] where ET=[Sow to harvest rainfall] + [change in soil water]
[c] TE=Transpiration Efficiency [Yield/(ET-60)] (the slope of frontier assuming evaporation E of 60mm)
[d] S1= the sowing time at which the maximum yield used for WUE calculations was observed

Crop yield

Crop yield at the different sites reflected the amount of water available to the crops, and the incidence of frost. Maximum yield at the sites ranged from 6.0 t/ha at Greenethorpe (high water availability and no frost) to 1.2 t/ha at Condobolin (dry and frosty site) (Figure 1). The main effects of sowing date and variety were highly significant ($P<0.001$) at most sites, with significant interactions at all sites except for Greenethorpe and Breeza. At the high yielding Greenethorpe site, yield was highest in all varieties from the earliest (April 1) sowing, and declined by 50 kg ha^{-1} day^{-1} as sowing was delayed. At the other sites, highest yields were achieved from both early (April 1) and mid-April sowing (April 10-16), although the specific variety that achieved that yield varied with site and sowing date. For example at Junee, Ganmain and Condobolin the fastest developing variety Hyola575CL suffered a yield penalty when sown on April 1, but was among the highest yielding in mid-April. In contrast the variety 45Y88CL (Junee and Ganmain) and 44Y87CL (Condobolin) had similar or higher yield when sown in early April compared to mid-April. With the exception of the dry and frosty Condobolin site, overall yields for all varieties declined after mid-April.

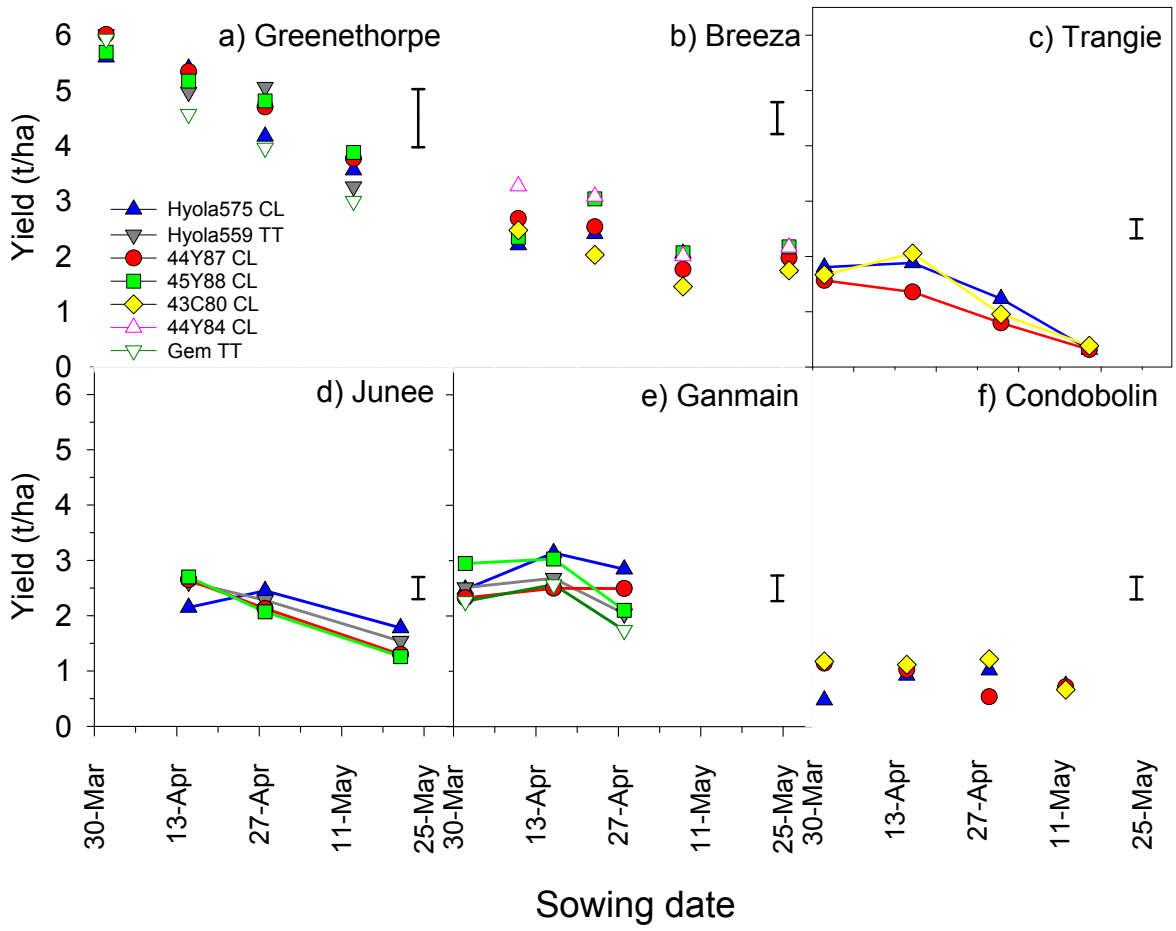

Figure 1. The effect of sowing date on the seed yield of a range of spring canola cultivars at 6 sites in eastern Australia in 2014. The vertical bars show the LSD (P<0.05).

Water Use Efficiency

The WUE and TE at Greenethorpe, Breeza and Junee were calculated using in-crop rainfall and the change in soil water measured from sowing to harvest (Table 1). At the other sites, starting soil water use was estimated from fallow rainfall and final soil water assumed to be negligible due to the prolonged, dry spring. Estimated maximum WUE and TE in Table 1 are calculated for the highest yielding combination of sowing date and variety at each site. The WUE ranged from 5.1 to 13.6 kg/ha/mm, while the TE calculated assuming a maximum evaporation (E) of 60 kg/ha/mm ranged from 7 kg/ha/mm at the hot, dry and frosty site at Condobolin, to 15.7 kg/ha/mm at Greenethorpe.

Figure 2 shows the relationship between crop yield and seasonal water supply of the six 2014 early sown crops alongside data published by Robertson and Kirkegaard (2005) for a series of experimental canola crops grown between 1991 and 2003. The crops were considered to have achieved water-limited potential, with the variation observed mostly due to differences in rainfall distribution and sowing date. The highest levels of TE above an estimated evaporation of 120mm for that data set was around 15kg/ha/mm (upper black dotted line) while the lower boundary was around 8 kg/ha/mm. Interestingly the six crops sown in April (17 to 30) within that dataset all lie close to the upper TE boundary shown. The results for the 2014 crops (red dots), with the exception of the dry frosty site at Condobolin, all fall on or above the upper boundary shown by Robertson and Kirkegaard (2005). Given the relatively dry 2014 season and the reliance on subsoil water, it is likely the evaporation component was lower than the 120mm assumed by Robertson and Kirkegaard, and the red dashed line in Figure 2 assumes 60mm evaporation and TE of 15.0. Early-sown hybrids are clearly pushing the boundaries of previously reported WUE through lower E and high TE.

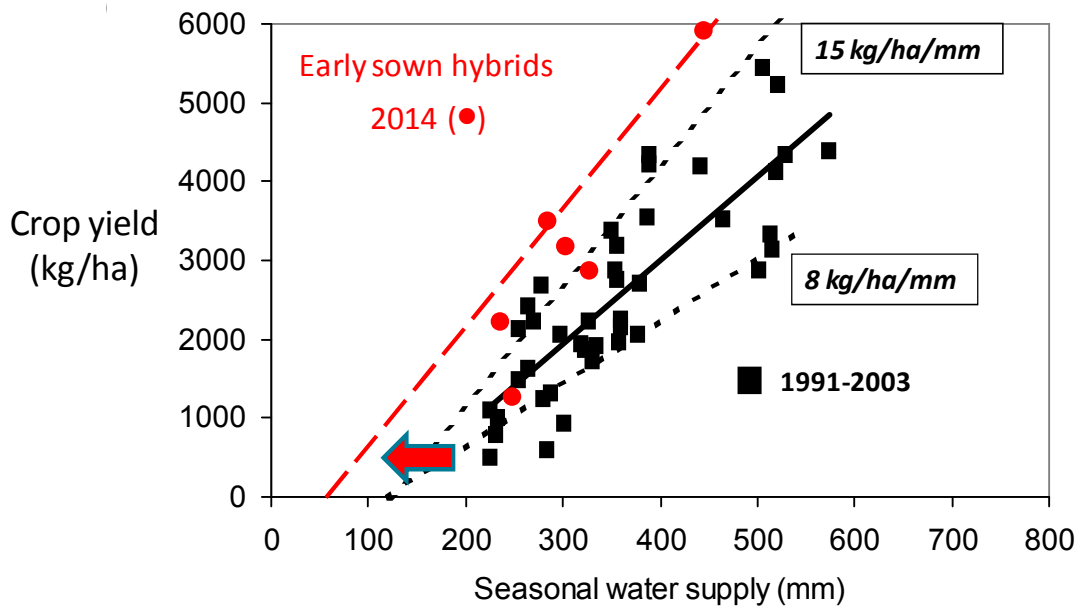

Figure 2. **The relationship between yield and seasonal water supply (in-crop rainfall + change in soil water) for 42 well-grown experimental canola crops in southern NSW between 1991 and 2003 (black squares). The TE ranged from 8 to 15 kg/ha/mm above an assumed evaporative loss of 120mm (black dotted lines). The early-sown hybrids in 2014 (shown as red dots) pushed the boundary (data from Table 1), presumably due partly to lower evaporative loss E (red arrow) along with high TE.**

Conclusion

In 2014, despite an unfavourable season with a warm May (leading to rapid development), significant late-winter frost events and dry spring, early-sown canola crops were able to equal, and in many cases exceed the yield of main season (25 April-sown) crops. The response of specific varieties to early sowing was critical. Spring varieties that were relatively slow to develop (e.g. 45Y88 CL) had their highest (or equal highest) yield from April 1 sowing at all sites, despite the dry spring and harsh late-winter frosts at some sites. Varieties that were relatvely fast to develop (e.g. Hyola575CL) should be avoided for early sowing situations, as they flower early in winter, exposing developing pods to frost, and may also generate insufficient biomass prior to the reproductive phase to support optimum yields. The early-sown hybrid varieties used water very efficiently, often exceeding the upper boundaries reported in previous studies. Though the rainfall pattern may have contributed to lower evaporation, other factors contibuting to efficient water use were the rapid ground coverage of early-sown hybrids, deeper rooting, higher transpiration efficiency and the avoidance of late-season heat and drought. Tactical agronomy packages that manage the risks and costs in early sowing systems (weeds, disease, input costs) are the target of ongoing research.

Acknowledgements

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The critical period for yield determination in chickpea

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Abstract
Chickpea is the most important grain legume crop in Australia; however biotic stresses such as Aschochyta blight and abiotic stress such as water and heat stress cause yield instability. Yield responds to the intensity, timing and duration of the stress. Crop species have a specific critical period for yield determination, where vulnerability to stress is greatest. The critical period for chickpea is previously unreported. To bridge this gap we exposed two chickpea varieties, PBA Slasher and PBA Boundary to sequential 14 day shading periods and compared their yield to the yield of unshaded controls in three different environments. Unshaded controls yielded between 2.9 and 3.1 t ha-1. Shade treatments reduced yield early in the season from emergence to the beginning of the critical period, 300◦Cd before flowering (base temperature = 0◦C), which differs from other species such as field pea and lupin which showed no early season yield loss. The critical period was centered 100◦Cd after flowering and was at least 800◦Cd duration. The majority of yield variation was accounted for by seed number, which was not related to seed size. The majority of the variation in seed number prior to the critical period was accounted for by pod number, while within the critical period seeds per pod also accounted for variation in seed number. Around the end of flowering, 400◦Cd after beginning of flowering, seeds per pod was the main component accounting for variation in seed number.

Keywords
Yield determination, critical period, yield components, stress, seed number, seed size

Introduction

Chickpea (*Cicer arietinum* L.) is grown predominantly in south Asian and Mediterranean environments where yield is constrained by abiotic stresses such as water deficit and extreme temperatures (Knights and Siddique, 2003, Kashiwagi et al., 2006, Leport et al., 2006). The effect of abiotic stresses on crop yield depends on the intensity, timing and duration, emphasising the importance of determination of the critical period for yield determination in major crops. Species specific critical periods have been determined for cereals; wheat, barley, triticale and maize, sunflower and the grain legumes; soybean, peas and lupin. In cereals the critical period has been commonly identified around the stage leading up to anthesis in barley (Arisnabarreta and Miralles, 2008), has extended into flowering for wheat and triticale (Estrada-Campuzano et al., 2008, Fischer and Stockman, 1980, Fischer, 1985), and even further post anthesis for maize (Cerrudo et al., 2013). In grain legumes, the majority of the critical period occurs further into seed set and filling with soybean identified as R1 (beginning of flowering) to R5 (beginning of seed set) and 10 days before R1 to R5 for lupin and field pea (Jiang and Egli, 1995, Board and Tan, 1995, Sandaña and Calderini, 2012).

The aim of this study was to determine the critical period for yield determination in chickpea using the most common method, sequential periods of shading to cause source reduction.

Methods

Plant material, environments and experimental design

Two chickpea varieties (PBA Slasher and PBA Boundary) were grown in three environments.: Roseworthy (34º52'S, 138º69'E) sown on 7th June, Turretfield (34º33'S, 138º49'E) at recommended sowing date (14th June – TOS 1) and Turretfield late sown (9th of July – TOS 2). Daily weather data was obtained from the Queensland Government, Long Paddock website (http://www.longpaddock.qld.gov.au/silo/). Thermal time was calculated from daily mean temperature using a base temperature of 0ºC (Berger et al., 2006).

A split-plot design with four replicates was used where varieties were allocated to main plots and shading treatments, including unshaded controls, to randomised subplots. Shading treatments lasted for 14 days each, and were designated sequentially from 1 to 8, starting at 31 days (353 ºCd) after sowing at Roseworthy and

24 days (251 °Cd) after sowing at Turretfield TOS 1. Turretfield TOS 2 had a shorter growing season and had 6 shading treatments in sequence beginning 35 days (399 °Cd) after sowing. Plants were hand harvested at maturity. The shades were constructed from black shade cloth that intercepted 90% of solar radiation.

Traits

Weekly phenology observations recorded time of first flower (FF), fifty percent flowering (50F), pod emergence (PE), and end of flowering (EOF). Maturity was scored when 50% of pods in a plot had matured. Phenological stages are expressed on a thermal time scale. Yield and yield components were measured including pod number, pod weight, seed size, seeds per pod, shoot biomass and the derived traits pod wall ratio PWR (pod wall weight/ whole pod weight, (Sadras et al., 2013) and harvest index HI (seed /shoot biomass).

Results

Seed yield and components

There was no difference between the yield and yield components of PBA Boundary and PBA Slasher in any of the environments with the exception of seed number and seed size at Turretfield. Shading affected yield and all yield components, with the exception of Turretfield TOS 1, where seed size and pod wall ratio where unaffected. There was no interaction between shade and variety on any trait, except seed size at Roseworthy and Turretfield TOS 2. Yield had a strong positive correlation with both biomass and harvest index. The relationship between harvest index and biomass varied between environments, with a positive relationship at Turretfield and no relationship at Roseworthy. Yield was closely related to seed number and unrelated to seed size. Seed number was related with both pod number and seeds per pod, but the relationship was stronger with pod number, reflecting the greater plasticity of this trait.

Critical period

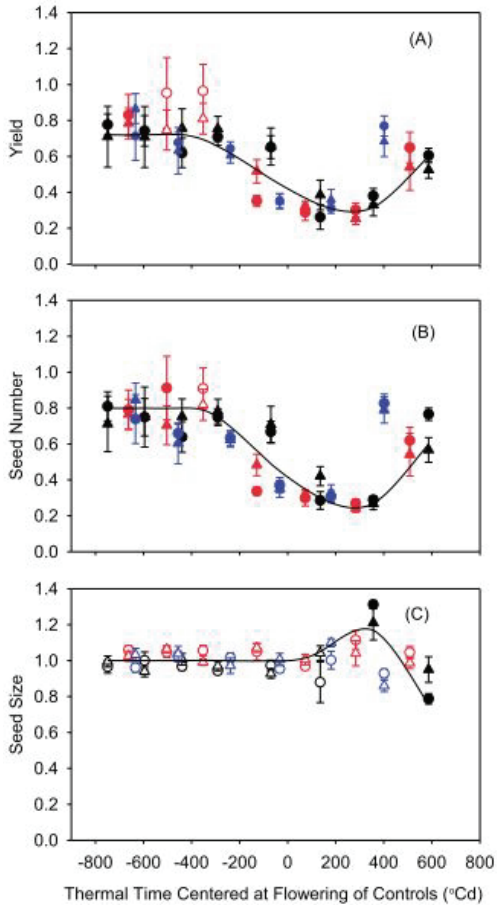
The effect of time of shading on yield and yield components was consistent for both varieties and was consistent across environments on a phenological scale (Figures 2, 3). Yield decreased for most shading treatments, with reductions in response to early shading of between 20 and 30% up to approximately 300oCd before flowering. The greatest reductions started approximately 300oCd before flowering and increased to 75% approximately 200oCd after flowering (Fig. 2A). After this critical point, yield increasingly recovered toward maturity. The most critical period for yield determination, with a reduction of at least 40%, spanned the window of 800oCd centred 100oCd after flowering.

Reduction in yield was almost fully accounted for by reduction in seed number (Fig. 2A vs 2B). Seed size was largely unaffected by shading except for a ~20% increase when shade was imposed 200-300 oCd after flowering and a ~20% decrease after this time (Fig. 2C). Seed number correlated with both pod number and seeds per pod, with no trade-off between the components of seed number. Comparison of Figures 2B and 3 shows that reduction in seed number was associated with (i) pod number from crop establishment until ~450 oCd after flowering, (ii) both pod number and seeds per pod between ~300 oCd before and ~450 oCd after flowering, and (iii) seeds per pod after ~450 oCd after flowering. Reductions in seed per pod were the result of both empty pods and fewer seed per pod.

Discussion

The critical period for chickpea differed with other grain legumes such as lupin, field pea and soybean, where the majority of the critical period occurs after flowering (Sandaña and Calderini, 2012, Jiang and Egli, 1995, Board and Tan, 1995). The reasons for the broader critical period in chickpea are unknown, and deserve further research.

The response of seed number and seed size to shading was in accordance with empirical evidence and current theory of crop yield determination (Sadras and Denison, 2009, Sadras, 2007, Sadras and Slafer, 2012, Andrade et al., 2005). A significant increase in seed size was associated with shading around pod emergence. This may be due to preferential carbohydrate partitioning to developing seeds that have passed the final stage in seed abortion (Munier-Jolain et al., 1998), rather than younger flowers and embryos. Pod number contributed more to the variation in seed number than seeds per pod. This is expected from the relatively low variation in seeds per pod in chickpeas compared to other legumes.



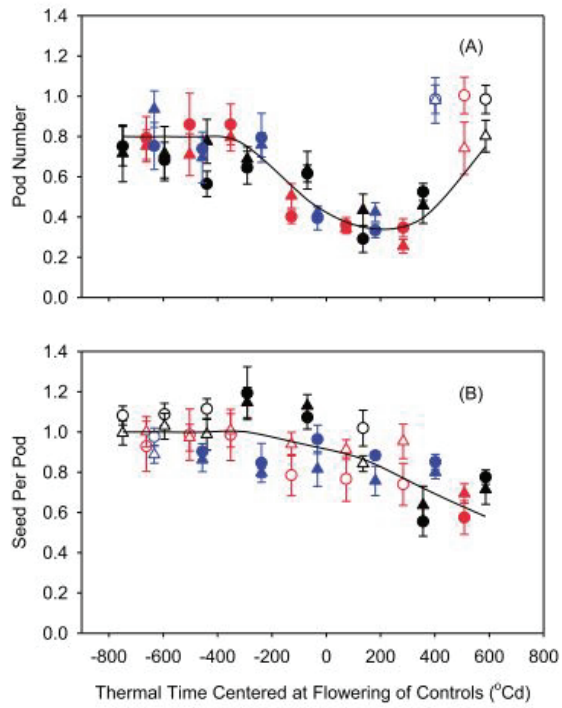


Fig. 1. Effect of timing of shading on (A) yield, (B) seed number and (C) seed size of chickpea PBA Boundary (circles) and PBA Slasher (triangles) compared to unshaded controls, at Roseworthy (black), Turretfield TOS 1 (red) and (C) Turretfield TOS 2 (blue). Open symbols are not significantly different from the control, while closed symbols are significantly different. The lines are spline curves fitted by eye. Error bars are ±S.E and are not shown when smaller than symbol. The phenological scale is based on the unshaded controls.

Fig. 2. Effect of timing of shading on (A) pod number and (B) seeds per pod for chickpea PBA Boundary (circles) and PBA Slasher (triangles) compared to unshaded controls, at Roseworthy (black), Turretfield TOS 1 (red) and Turretfield TOS 2 (blue). Open symbols are not significantly different from the control, while closed symbols are significantly different. The lines are spline curves fitted by eye. Error bars are ±S.E and are not shown when smaller than symbol. The phenological scale is based on the unshaded controls.

Conclusions

This research has identified the critical period for yield determination and the associated critical periods for yield components. This knowledge will allow for more targeted stress mitigation practices, e.g. combining sowing date and cultivar phenology to reduce the likelihood of severe stress in the critical window. Increased knowledge of the critical period will also enhance the ability of breeders to screen for stress tolerance with more targeted stress impositions.

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Adapting rain-fed sorghum agronomy to breeding progress – Cropping system model parameterisation

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Abstract
Over the last decades, there has been considerable investment from the private and public sector in genetic improvement of sorghum hybrids, but the high yield potential of these new genotypes is not always achieved in farmers' fields. Matching these new genotypes to seasonally optimised crop management has the potential to increase productivity. One of the best ways to determine a hybrid's yield potential in a specific location, but also to identify best hybrid by environment by agronomic management combinations and to demonstrate benefits and trade-offs between productivity, investment and risks, is to use a crop model, such as APSIM (www.apsim.info). To enhance APSIM's ability to predict grain yield for various sorghum genotypes, growth and development parameters of new hybrids have to be determined. Here we present flowering time data for one previous and eleven newly-released sorghum hybrids that were parameterised in specially-designed experiments with five different sowing times and the fit between model-predicted and observed values. This information, together with other growth parameters, will be used to parameterise the model to improve APSIM's ability to simulate yield of the new sorghum types.

Key words
Anthesis, thermal time, sowing date.

Introduction

There are many new sorghum hybrids with improved yield potential available to growers in the North-eastern grain belt of South-east Queensland and Northern New South Wales. To ensure these genetic improvements actually lead to greater farm productivity we need to be able to determine whether farm yields are close to the potentially achievable yields as determined by genetic (i.e. hybrid specific) and agro-ecological (i.e. location specific soil and climatic) factors. By definition, yield potential (Yp) describes the maximum yield for a specific location that can be achieved with a hybrid when water and nutrients are non-limiting. For rain-fed crops, water-limited yield potential (Yw) as determined by water availability, may be used (van Ittersum et al., 2013). The gap between potential yields for a specific location and average farm yields in that region is described as the yield gap. Yield gap analysis provides the basis for the study of factors that might limit average farm yields and is therefore essential in identifying opportunities for productivity gains. There are several methods to estimate Yp or Yw, but crop simulation modelling is the most reliable of them, because crop models can account for interactions among crops, weather, soils and management (van Ittersum et al., 2013).

We will use the Agricultural Production Systems Simulator (APSIM www.apsim.info) to develop productivity-investment-risk profiles for promising combinations of genotype and crop management practices for sorghum across the South-east Queensland and Northern New South Wales cropping zones. A clear synthesis of benefits and trade-offs between productivity, investment and risks will be developed to support farmers' decisions on closing the yield gap. It is important, however, that simulations of Yp and Yw are based on recently released cultivars that are used by the farmers in the region (Grassini et al., 2015).

APSIM was initially developed in Australia in the 1990s and consists of individual modules, such as soil modules, a management module and various crop modules (Holzworth et al., 2014). In the crop modules, canopy development and growth are simulated using thermal time targets for various developmental stages (e.g. thermal time to anthesis or grain maturity) (Hammer et al., 1993). To enhance the capacity of APSIM to simulate yield of newly released hybrids, we parameterised eleven recent commercial sorghum hybrids plus (Pacific Seeds) one of the sorghum hybrids that APSIM simulations are currently based on.

Here we present data on thermal time targets for the growth period from emergence to anthesis for these twelve hybrids. There were significant (P<0.0001) hybrid by sowing date interactions for thermal time to anthesis and values ranged from 544 to 731 degree days.

Materials and methods

Five phenology experiments (PHEN 1 to PHEN 5) sown at five different sowing dates (Table 1) were conducted at Hermitage Research Facility in South-East Queensland (28°21' S, 152°10' E; 480 m above sea level) during the 2014-15 sorghum growing season.

In each phenology experiment twelve sorghum hybrids with contrasting maturity types (as previously classified) from three commercial seed companies (Nuseed, Pacific Seeds and Pioneer) were sown in a row-column design with two replications.

Experimental plots were 3 m long and contained four rows at 0.76 m row spacing and plant stands were thinned to 50,000 plants per hectare. All experiments were fully irrigated and enough nitrogen was applied to ensure non-limiting conditions.

Five plants from the two middle rows in each of the plots were tagged for regular observations. Emergence date was defined as the date when 50% of plants in 2 m of row had emerged. Anthesis was rated as the percentage of the panicle on the main stem of each tagged plant that was flowering and the date of anthesis was taken as the date when these ratings averaged 50% across the five tagged plants.

Hourly temperature data was collected from a weather station mounted next to the experiments. Thermal time was calculated using base temperature, optimum and maximum temperatures of 11, 30 and 42 °C, respectively (Hammer et al., 1993).

Table 1 Phenology experiments (PHEN 1 to PHEN 5) with sowing dates, average temperatures and average thermal time for the period from emergence to anthesis.

Experiment	Sowing date	Average temperature between emergence and anthesis of the 12 hybrids (°C)	Average thermal time from emergence to anthesis of the 12 hybrids (°C d)
PHEN 1	30/09/2014	21.8	646
PHEN 2	30/10/2014	22.7	658
PHEN 3	25/11/2014	22.6	638
PHEN 4	23/12/2014	22.1	675
PHEN 5	20/01/2015	21.8	657

Results and discussion

Average temperatures and accumulated thermal times from emergence to average anthesis date of all twelve hybrids were quite similar for each of the sowing dates (Table 1). Despite this, significant (P<0.000.1) sowing date by individual hybrid interactions were observed for thermal time to anthesis and some hybrids had more variable flowering times depending on sowing times than others (Fig. 1). The causes for this variation are yet to be investigated.

There were no significant differences in average thermal time to anthesis between the groups of different maturity types. Hybrids that were classified previously as early to medium maturity types on average reached anthesis after 630 growing degree days across sowing dates, while hybrids of medium and medium to late maturity types on average required 657 and 676 degree days respectively to reach anthesis.

The hybrid Buster, one of the hybrids that were previously parameterised for the APSIM model, flowered between 613 to 639 degree days across the five sowing times (Fig. 1). There were hybrids that flowered much sooner and others that flowered much later than Buster and thermal time targets for these hybrids were used to update the APSIM model.

Predicted versus observed times to flowering from simulations using these thermal time targets are shown for

all twelve hybrids (Fig. 2).

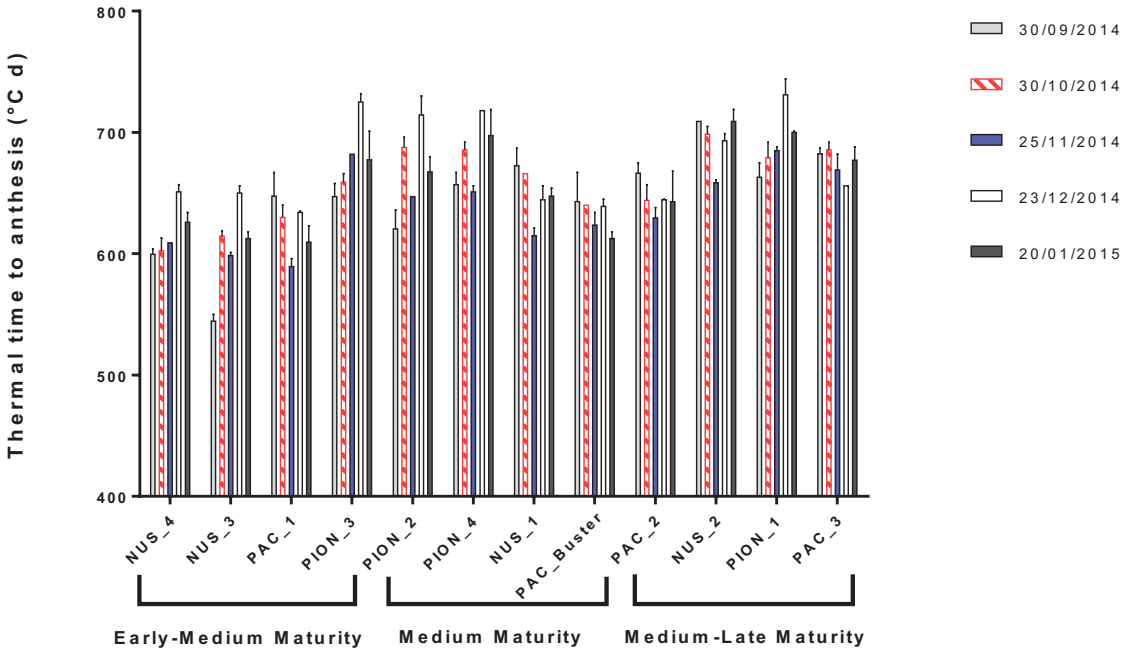

Fig. 1 Thermal time (°C d) to anthesis by sowing date for hybrids that were previously classified as early to medium maturity (NUS_4, NUS_3, PAC_1 and PION_3), medium maturity (PION_2, PION_4, NUS_1 and Buster) and medium to late maturity (PAC_2, PAC_3, NUS_2, PION_1). NUS=Nuseed, PAC=Pacific Seeds, PION=Pioneer. Vertical bars and error bars represent means and standard errors for the two replicates of each hybrid, respectively.

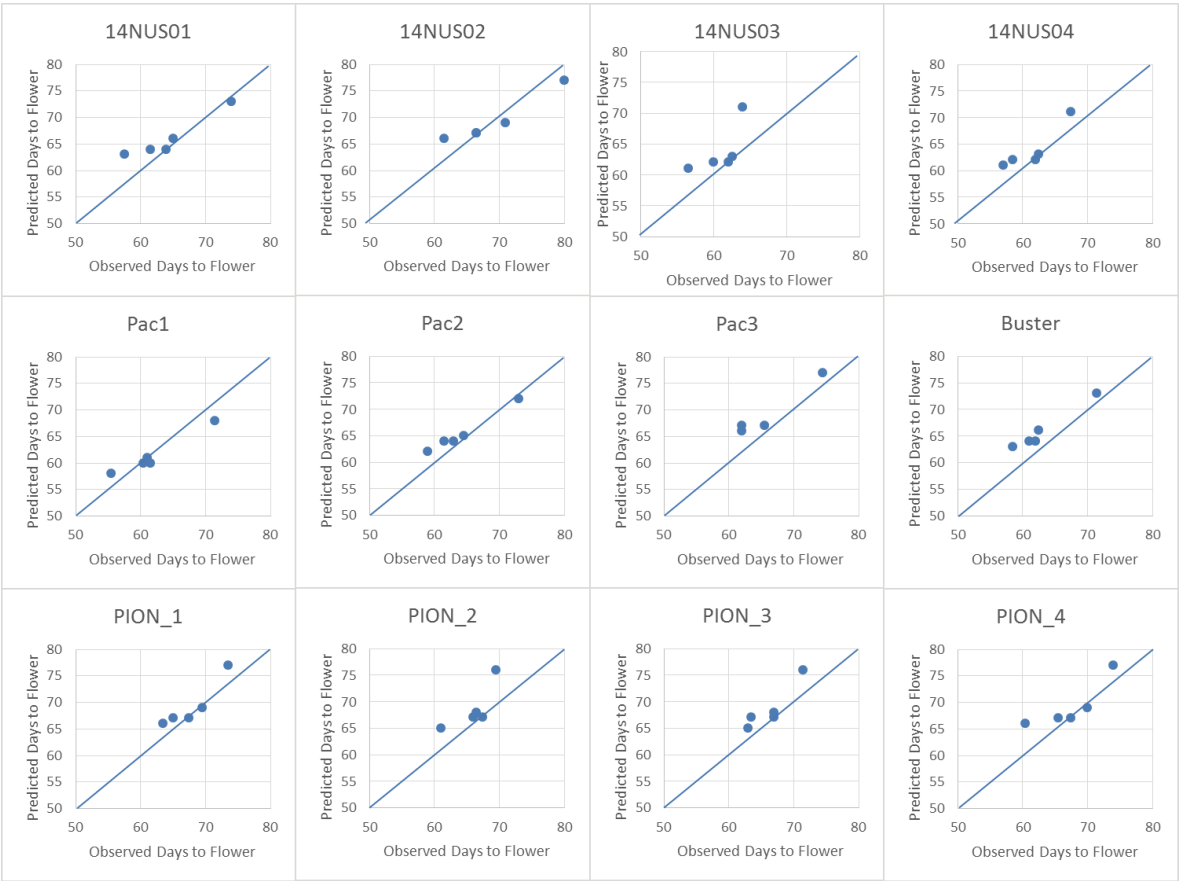

Fig. 2 Observed versus predicted days to flower from simulations with thermal time targets for individual hybrids. Lines equal identity lines.

Conclusions

In this paper we reported on just one of the parameters that are used in APSIM to simulate sorghum crop yield. The parameter (thermal time to 50% anthesis) showed significant hybrid by sowing time interactions and there were both hybrids that were significantly quicker in advancing towards anthesis and hybrids that were slower than the hybrid Buster, which was previously parameterised for the APSIM model.

This information will aid in estimating location-specific potential yields of current sorghum hybrids. This will allow us to match these new genotypes to seasonally optimised crop management taking into account risks and benefits of increasing investments with the aim of increasing productivity and economic returns for sorghum growers across the Queensland cropping zones.

Acknowledgments

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Physiological and biochemical attributes of *Camelina sativa* (L.) Crantz under water stress conditions

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Abstract
Drought stress is a serious threat for almost all crops including *Camelina*. The present study was consisted of two experiments. The first experiment was conducted in laboratory to screen out the two *camelina* accessions (V_1:611 and V_2:618) under different levels of osmotic stress (0,-0.2, -0.4,-0.6 and -0.8 MPa) created by using Polyethylene glycol 6000. The data regarding mean germination time, 50 % seed germination (T50), germination index and final germination percentage was recorded under normal and water stress conditions. The accession(V_1) 611 was identified as drought sensitive because it took more mean germination time and more time to 50% germination (T50), less germination index and less final germination percentage as compare to accession (V_2) 618 under osmotic stress . The second experiment was carried out in pots under rain-out shelter to investigate physiological and biochemical responses of camelina accessions (V_1:611 and V_2:618) under normal and water stress conditions. The data regarding photosynthetic rate, transpiration rate, stomatal conductance and chlorophyll contents was recorded. The treatment combination (V_2): 618 × 60% (F.C) showed more photosynthetic rate (2.56 μ mol m^{-2} s^{-1}), transpiration rate (0.98 μ mol m^{-2} s^{-1}), stomatal conductance (0.1033 μ mol mol^{-1}) and total chlorophyll contents (1.93 mg g^{-1}f.w.) which was statistically similar to the treatment combination (V_1): 611 × 100% (F.C) .In conclusion from both the experiments the accession (V_2): 618 proved more drought tolerant than accession (V_1) 611.

Keywords
Seed germination,gas exchange, chlorophyll contents, water stress, *Camelina sativa*

Introduction
Camelina sativa, belongs to family Brassicaceae, is a cold tolerant, heat tolerant, drought tolerant (Kyung et al. 2013) and nutrient use efficient crop (Zubr 1997). The growth, yield and oil quality of oilseed crops is affected by their tolerance to abiotic stresses such as heat and drought (Weiss 2000). Water stress is an important limiting factor that significantly affects agricultural productivity throughout the world especially in warm, arid and semi-arid regions. Selection of tolerant genotypes is one possible solution of problems caused by drought in plant production (Waraich et al. 2011). *Camelina*, being drought tolerant crop has the potential to become an important oil seed crop for sub-arid and irrigation water deficit areas (Waraich et al. 2013. *Camelina* crop requires minimum inputs being less responsive towards N, P and K application (McVay & Lamb 2008). Drought stress severely affects both morphology as well as metabolism of the plant (Mark and Antony. 2005). Water shortage induced by drought or osmotic stress changes morphology, gas exchange, water relations and chlorophyll contents which are interlinked with the initiation of defensive mechanisms in plant (Jackson et al. 1996). Learning about physiological mechanisms which enable plants to adapt to water deficit condition and maintain their growth and productivity under stress period could be helpful in screening and selection of tolerant genotypes (Zaharieva *et al*., 2001). Keeping in view the oil demands for Pakistan and big threat of drought stress, the present study was devised to study the response of *Camelina* to drought stress in Pakistan.

Materials and methods
Two experiments (First in laboratory and second in rainout shelter) were conducted to study the physiological and biochemical attributes of *camelina* sativa (L.) crantz under water stress conditions. To study the effects of Polyethylene glycol-6000 (PEG-6000) induced drought stress on seed germination indices of *Camelina*, first experiment was conducted in petri-plates in the stress physiology laboratory of the Department of Crop

Physiology, University of Agriculture, Faisalabad. Seeds of two c*amelina* accessions (V1:611 and V2:618) were obtained from the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. These two accessions of *Camelina* (V1:611 and V2:618) were sown in four concentrations of PEG-6000 @ 0, 5,10 and 15 g were dissolved in water to develop 0, -0.2, -0.4 and -0.6 MPa drought stress treatments. The seeds of two accessions of *camelina* were surface sterilized for five minutes with 10% Sodium hypochlorite solution to prevent any fungal attack and then rinsed thrice with distill water.

Twenty seeds of both *Camelina* accessions (V1:611 and V2:618) were placed in each petri plate between two layers of filter papers. The experiment was carried out in a completely randomized design (CRD) with three replications with (25/220C, day/night) temperature. Ten ml of PEG solution was applied daily in each petri plate to create osmotic stress after washing out the previous solution. Seed germination data was recorded daily for 7 days after the beginning of experiment. Mean germination time was calculated by following the formula of (Moradi et al. 2008): MGT= ∑Dn/∑n

The time to 50% germination (T50) was calculated by the following formula of (Coolbear et al. 1984)
The second experiment was conducted in pots and completely randomized design with three replications was used in the rainout shelter of department of crop physiology, University of Agriculture, Faisalabad. Before sowing sand was sun dried and sieved. Gravimetric method was employed to determine field capacity of sand. Each plastic pot (20cm ×16cm) was filled with 2 kg of sand and 15 seeds of both *Camelina* accessions (V_1:611 and V_2:618) were sown in plastic pots and then irrigated with distilled water. After sowing all pots were kept at field capacity level for obtaining good germination and emergence and then 20 days after sowing the plants were thinned out and uniform size healthy 10 plants were kept in each pot. Later on 10 days after thinning water stress was applied according to the specified drought stress levels (500 ml water for 100% field capacity and 300 ml water for 60% field capacity). Recommended rates of phosphorus and potassium (30 kg ha-1 and 60 kg ha-1 respectively) were applied at the time of sowing. Nitrogen (50 kg ha-1) was applied in two splits. Half nitrogen (25 kg ha-1) was applied at the time of sowing and remaining half was applied after 20 days of sowing.Data was recorded on gas exchange parameters and chlorophyll content.

Statistical analysis: All data was analyzed using software package of Statistix-9.1software. The mean values of plant responses were compared statistically by using least significant difference (LSD) test.

Results:Data pertaining to the effect of PEG induced osmotic stress on mean germination time, germination index, time taken to 50% germination and final germination percentage is presented in Table (1). Maximum mean germination time and T50 were recorded in the treatment combination -0.6MPa and 611genotype. Minimum value of mean germination time and T50 value were observed in 618 genotype under non-stress conditions. Maximum germination index and final germination % of (100%) were recorded in the 618 genotype under non-stress conditions while minimum germination index and final germination % were recorded in the 611genotype at -0.6 MPa.

Table No.1: Mean germination time (MGT), germination index (GI), time to 50% germination (T50) and final germination percentage of *Camelina* sativa genotypes under water stress conditions.

Parameters	Osmotic Stress	Genotypes		LSD 0.05
		V1:611	V2:618	
Mean Germination Time (MGT) Days	Control	4.16e	3.82c	0.63
	- 0.2 MPa	4.96c	4.47cd	
	-0.4 MPa	5.88b	4.95c	
	-0.6 MPa	6.28a	5.61b	
	-0.2 MPa	4.05b	4.10b	
	-0.4 MPa	3.30c	3.46bc	
	-0.6 MPa	3.19c	3.45bc	

Time taken to 50%Germination (T50) Days	Control	3.42c	3.23c	1.36
	-0.2 MPa	4.32bc	3.39c	
	-0.4 MPa	5.34b	4.10bc	
	-0.6 MPa	6.76a	4.13a	
Final Germination Percentage	Control	100a	100a	5.85
	-0.2 MPa	88.33cd	93.33bc	
	-0.4 MPa	91.67c	93.33bc	
	-0.6 MPa	85d	90.33cd	

Data for various gas exchange attributes are presented in Table (2). The data revealed that photosynthetic rate (*A*) , transpiration rate (*E*), stomatal conductance(*gs*) and sub-stomatal CO_2 concentration (*C*i) produced by accession V_2: 618 under drought stress (60% Field capacity (F.C) condition was statistically similar to camelina accession V_1 :611 under the well-watered conditions. Minimum *A*, *E*, *g*s and *C*i were recorded in camelina accession V_1 :611 under 60% field capacity (F.C).

Table.2: Net CO_2 assimilation rate, transpiration rate, stomatal conductance and substomatal CO_2 concentration of *Camelina sativa* genotypes under water stress conditions.

Parameters	Water Stress	Genotypes		LSD 0.05
		V_1:611	V_2:618	
Net CO_2 assimilation rate (μ mol CO_2 m^{-2} s^{-1})	100%FC	3.85a	2.99a	1.13
	60%FC	1.75b	2.56a	
Transpiration rate (m mol H_2O m^{-2} s^{-1})	100%FC	1.07a	0.97a	0.25
	60%FC	0.33b	0.98a	
Stomatal conductance (mol m^{-2} s^{-1})	100%FC	0.10a	0.10a	0.02
	60%FC	0.06b	0.10a	
Substomatal CO_2 Concentration (μ mol mol^{-1})	100%FC	385.33a	377.32a	10.45
	60%FC	344.29b	376.23a	

Data for chlorophyll contents showed that chlorophyll *a*, *b* and total chlorophyll contents recorded in accession V_2: 618 at 60% Field capacity (F.C) were statistically at par with accession V_1 :611 under the normal watering. However minimum chlorophyll *a*, *b* and total chlorophyll contents were recorded in accession V_1 :611 under drought stress conditions (60% FC) (Table 3).

Table.3: Chlorophyll *a*, *b* and total chlorophyll contents of *Camelina sativa* genotypes under water stress conditions.

Parameters	Water Stress	Genotypes		LSD 0.05
		V_1:611	V_2:618	
Chlorophyll a (mg g^{-1} f.wt.)	100%FC	1.88a	1.85a	0.10
	60%FC	1.69b	1.83a	
Chlorophyll b (mg g^{-1}f.wt.)	100%FC	0.81a	0.75a	0.09
	60%FC	0.63b	0.74a	
Total Chlorophyll Contents	100%FC	1.98a	1.91a	0.10
	60%FC	1.56b	1.93a	

Discussion

In the present study seed germination indices were calculated under various levels of osmotic stress created by using PEG-6000 in the laboratory. The most important and critical stage in the life cycle of plants is germination (Ahmed et al. 2009). In our study PEG induced osmotic stress reduced seed germination percentage and it is according to the finding of Gamze et al. (2005). Water stress not only affects seed germination but also increases mean germination time in crop plants (Willanborb et al. 2004). The results of our second experiment showed that drought limits the photosynthesis by reducing the stomatal conductance in camelina. Similar results were also reported by Lawson et al. (2003). In water deficit situation reduction in chlorophyll contents especially in older leaves due to dehydration could be another reason of reduced photosynthesis under water deficit situations (David et al. 1998). Decrease in chlorophyll contents due to water stress is expected because it causes loss of pigments and disorganization of thylakoid membranes (Ladjal et al. 2000). Reduced lamellar content of the light harvesting chlorophyll **a**/**b** protein might cause reduction of chlorophyll content in water stressed plants (Randall et al. 1977).

Conclusion

This study revealed that under PEG induced water stress *camelina accession* V_2: 618 showed good germination and proved more drought tolerant as compared to *accession* V_1: 611. Similar trend was observed in the second experiment when *Camelina* was grown in pots under rainout shelter. *Camelina accession* V_2: 618 performed better under drought stress because gas exchange, chlorophyll contents and water relation parameter values were statistically at par with non-stress conditions. Consequently under drought stress conditions *accession* V_2: 618 was more drought tolerant as compared to *accession* V_1: 611.

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Exotic plant pests – a threat to the sustainability of Australia's grains industry

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Abstract
Exotic plant pests (EPPs) threaten production, market access and sustainability of Australian plant production systems. For the grains industry there are over 600 identified EPPs of which 54 are considered high priority, posing a significant threat. Despite Australia's geographical isolation and strong quarantine systems, the threat from EPPs has never been higher with the increasing levels of travel and trade, emphasising the need for improving our efforts in prevention, preparedness and surveillance for EPPs.

An EPP considered an "extreme" risk to Australia's grains industry is the disease Karnal bunt (*Tilletia indica*). With a significant number of countries having import restrictions relating to Karnal bunt, extreme economic consequences are expected to occur if the disease was to become established, primarily due to loss of international market access. Russian wheat aphid (RWA) (*Diuraphis noxia*), another high priority EPP, threatens the sustainability of cereal production systems, with yield losses up to 80% recorded in countries where it's established. Different biotypes of RWA exist overseas, as do cereal varieties with varying resistance levels to different biotypes. This makes pre-emptive breeding for resistance difficult. Therefore insecticides remain important for managing RWA. The national Grains Farm Biosecurity Program plays an instrumental role in the awareness of EPPs and implementing biosecurity best practice through extension, education and training. The program places a heavy importance on the role of surveillance and reporting by industry personnel in order to detect an incursion early, increasing the likelihood of eradication and reducing its impact on industry and community.

Key words
Grains biosecurity, Russian wheat aphid, Karnal bunt, Grains Farm Biosecurity Program

Introduction

Exotic Plant Pests (EPPs) are invertebrates or pathogens not currently in Australia, which pose a significant economic threat regionally or nationally to a plant production industry and/or the environment. In regards to the Australian grains industry there are over 600 identified EPPs for the 25 leviable grain crops that encompass our temperate and tropical cereals, oilseeds and pulses. Any one of these EPPs could have significant impacts on the sustainability of grains production in Australia. Some EPPs are likely to significantly impact on yield (e.g. Russian wheat aphid) while others (e.g. Karnal bunt) would have a detrimental impact on our market access.

Many levels of government and industry work together as part of the biosecurity continuum that helps protect Australian producers from a wide range of exotic pests and diseases. However threats cannot be fully eliminated and the growth of travel and trade puts increasing pressure on the systems for continued efforts in prevention, preparedness and surveillance for EPPs.

This paper briefly discusses the plant biosecurity continuum within Australia and priorities within the grains industry. It highlights case studies for two grains EPPs and the efforts and outcomes of the Grains Farm Biosecurity Program, a national initiative, funded by Grain Producers Australia and state governments, in biosecurity awareness and risk mitigation.

The biosecurity continuum

Sound biosecurity systems are crucial to the success of the Australian grains industry in maintaining market access, sustainability of agricultural production, food security and integrity by safeguarding the industry

from EPPs. 'Biosecurity is a national priority, implemented off-shore (prior to goods arriving in Australia), at the borders (national and state), regionally and on farm' (Bellati et al. 2012). Australia's geographical isolation and strong biosecurity system has ensured that many pests of crop production (including post-harvest storage) overseas are not present in Australia. Freedom from EPPs provides both a yield advantage as well as real trade benefits for Australian crop production industries such as grains.

Importantly, national and state biosecurity systems are complemented and supported by measures carried out at the industry and regional level. As risks of new pests entering Australia can never be totally eliminated industry biosecurity is regarded as a shared responsibility where all links in the production and supply chain engage and take responsibility for minimising biosecurity risks that are within their control. Growers implementing farm biosecurity practices, agronomist, researchers and other service providers including contractors can all play an important role in safeguarding the industry at a farm, regional and national level. An aware and trained grains industry has the capacity to minimise the risks posed by new pests, and respond effectively to any pest threats that would impact on the future sustainability and viability of the industry.

The grains industry peak body, Grain Producers Australia (GPA), plays a significant role on behalf of industry. As the signatory to the Emergency Plant Pest Response Deed (EPPRD), GPA consult with federal and state governments on biosecurity issues pertaining to the grains sector.

Pest Risk Analysis

In order to prioritise mitigation activities and focus on the most damaging pests, a Pest Risk Analysis (PRA) was undertaken on each of the 600 identified EPPs (PHA 2014). PRA's take into account a range of factors such as the potential for the pest to gain entry into Australia (risk pathways); how easily it could become established and spread throughout the cropping areas; the estimated damage it could cause (e.g. yield loss, management costs, loss of market access or downgrading of product) and; the potential economic threat and feasibility of eradication of each pest. From this PRA process, 54 EPPs are considered high priority meaning they pose a high to extreme risk of causing significant impact to the grains industry if they were to become established in Australia (PHA 2014).

By identifying key EPPs a pre-emptive approach may be taken to risk management. Identification of high risk pests also assists in the implementation of effective community awareness campaigns, targeted biosecurity education, training and surveillance programs for industry stakeholders, pre-emptive breeding for resistance in host varieties and the development of pest-specific incursion response plans.

Case study 1: Karnal bunt – overall risk Extreme

Of the 54 high priority EPPs identified for the grains industry, Karnal bunt (*Tilletia indica*) is regarded as the highest pest threat for the grains industry. Karnal bunt is a fungal disease affecting grain quality producing a characteristic 'dead fish' odour and discolouration of grain. Hosts include wheat, durum wheat and triticale, where only a few spores are enough to make a product unfit for human consumption. The disease differs from other bunts and smuts present in Australia, as the grains are only partially replaced by Karnal bunt spore masses, rather than a total replacement of the grain by spores (Wright et al. 2006).

Currently, Karnal bunt is distributed throughout the world in a number of regions, including Asia, the Middle East, Africa, North America and South America with a number countries having trade restrictions in place for this pest (Wright et al. 2006).

Impact

Karnal bunt has caused substantial economic loss where it occurs overseas and if it were to become established in Australia, the economic impact is expected to be extreme. Loss of market access due to reduced grain quality, and the fact many countries consider the disease as a quarantine pest would see a significant impact upon the industry and Australia (Wright et al. 2006).

Murray and Brennan (1998) estimate the cost of declined quality of loss of markets to be worth 17% of the value of production in Australia. Other impacts may arise from costs associated with planting restrictions that may be imposed in the case of an incursion, as well as costs resulting from testing and control, cleaning for grain shipments and machinery and research such as plant breeding (Murray & Brennan 1998).

Incursion potential
The entry potential of Karnal bunt into Australia is rated as low, however a number of risk pathways have been identified that may facilitate entry. The more likely entry pathways are the importation of bulk grain and fertiliser, and agricultural machinery that are contaminated with spores. Travellers also have to be taken into consideration, especially those travelling from India and USA into Australian farming areas (Wright et al. 2006).

Climate modelling has been used to estimate the potential distribution of Karnal bunt in Australia, through analysing the development and lifecycle of the disease and associated climatic factors in current areas of distribution. Models indicate that a large proportion of Australia's wheat growing regions are climatically suitable for Karnal bunt to establish and develop (Murray & Brennan 1998).

Case study 2: Russian wheat aphid – overall risk High
Russian wheat aphid (*Diuraphis noxia*) is a major pest of barley and wheat but can attack most cereal crops. Russian wheat aphid (RWA) can cause significant yield losses if not controlled, especially in barley which is more susceptible. It is absent from Australia, but is found in most other major wheat growing regions including Russia, the Middle East, North and South America, Asia, Africa and most countries bordering the Mediterranean.

USA incursion
Since the first detection of RWA in South West USA in 1986, the total economic damage due to the pest has exceeded $1 billion. These damages include costs from crop losses, cost of pest control, and lost revenue to rural economies throughout the seventeen affected western states. The barley industry in the USA has been severely impacted upon by RWA since its incursion. Barley is very susceptible to RWA, resulting in the rapid decline of malt barley production with it virtually ceasing in badly affected areas (M Christopher 2014, pers comm., 17 April). It is not unreasonable to expect a similar impact in Australia if RWA was to become established.

Impact
Climatic modelling indicates that RWA would spread rapidly and become established across most of the major cropping regions within Australia. Estimates of crop damage range from 25-50% and up to 80% for some regions (Hughes & Maywald 1990).

A range of biotypes exist throughout the world where RWA is distributed, with 8 biotypes in the USA alone (Puterka et al. 2014). This variation poses a serious threat to Australia's barley and wheat production, as an incursion's origin will influence the level of resistance that will be available in our varieties. As such, GRDC (project UMU00029) are conducting research for pre-emptive breeding to develop wheat and barley varieties with RWA resistance with wide adaptation to Australia's grain growing regions (GRDC 2011).

Incursion potential
A Pest risk analysis conducted by PHA (2012) rated the entry potential for RWA as medium. However more recently expert entomologists suggest that entry potential more realistically may be considered low due to Australia's geographical isolation from countries where RWA is present, resulting in a low probability of entry via wind dispersal (M Christopher 2014, pers comm., 17 April). Overwintering eggs may be transported on harvested grains or fodder, however eggs are only produced in some populations, and as Australia does not import large volumes of these materials this is considered very unlikely (PHA 2012).

The Grains Farm Biosecurity Program – a national awareness and risk mitigation initiative
The Grains Farm Biosecurity Program (GFBP), initiated in 2007 program contributes to the grains industry's risk mitigation activities, and promotes a shared responsibility involving governments, industry and community.

The national GFBP has aligned key awareness messages and education objectives to current grains industry extension programs, in order to deliver grains biosecurity training and education seamlessly. A critical element to the success of these strategic alliances is "value adding" to existing program content, where biosecurity messages and exotic pest identification information is embedded within industry training programs such as Pulse Australia best management practice accredited workshops (Bellati et al. 2010).

Biosecurity – a shared responsibility

Biosecurity is everyone's business and must be considered in our day to day activities, especially when working in the field and travelling between production areas. Surveillance, hygiene and record keeping are important and practical tools to implement in order to practice good biosecurity. An awareness of key biosecurity threats, both endemic and exotic to Australia, associated with your industry can aid in early detection of a pest.

In order to detect a pest early, increasing the chance of eradication or effective management, routine surveillance and monitoring of crops and production areas is necessary. Surveillance is not only important for the management of endemic pests; it has now come to the forefront for pest status requirements for export markets. There is a need to provide scientific evidence of 'proof of absence' from key exotic pests, and surveillance data both specific and general, contributes to this required proof (Bellati et al. 2012). Surveillance at the farm level contributes essential information to regional biosecurity efforts, and ultimately to the national status of a pest. In order to gather the farm level data, the grains biosecurity officers of the GFBP rely on volunteer surveillance by a network of agronomists, researchers and other key stakeholders.

Agronomists and growers travelling overseas on farm tours and entering fields pose a high risk when returning to Australia and production areas. Awareness of high risk pests in other areas of the world, such as RWA in the USA, and practicing good hygiene such as leaving clothes behind, or making sure they are laundered sufficiently before returning are important and must be considered.

Conclusion

Awareness and surveillance are key to ensure early detection of an exotic plant pest incursion, however must be complemented with timely reporting of a suspect EPP. As the grains industry is a signatory to the Exotic Plant Pest Response Deed, there are obligations in order for reporting of suspects. Under some state government plant health acts, there is also a legal obligation to report a suspected exotic pest. A reporting mechanism includes the Exotic Plant Pest Hotline (1800 084 881), a national number which will automatically redirect the caller to the state department of primary industry they are in.

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High crown rot risk – should growers plant barley or wheat?

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Abstract

Twenty replicated field trials were conducted between 2009 and 2014 where both the bread wheat variety EGA Gregory and the barley variety Commander were included. All trials had inoculated versus un-inoculated treatments for crown rot with two separate sowing dates in five trial sets. In total this provided 23 comparisons between EGA Gregory and Commander in the presence of high crown rot infection. In 13 of 23 comparisons (57%), Commander provided a yield benefit over growing EGA Gregory (range +0.28 to +2.20 t/ha; avg. +0.95 t/ha). In 7 of 23 comparisons (30%), the difference in yield between Commander and EGA Gregory was not significant. In three comparisons (13%), Commander was significantly lower yielding than EGA Gregory (range -0.33 to -0.77 t/ha, avg. -0.48 t/ha), likely due to stress occurring earlier in the season. Barley tends to yield better in the presence of crown rot infection due to its earlier maturity relative to bread wheat, providing an escape mechanism which reduces its exposure to evaporative stress during grain filling. Delaying the sowing time of barley can remove this escape mechanism. If forced into planting a cereal crop in a high crown rot risk situation then some barley varieties may provide a yield advantage over bread wheat in that season, provided evaporative stress during vegetative growth stages does not occur. However, this decision will only potentially maximise profit in the current season. Growing barley over bread wheat will not assist with the reduction of crown rot inoculum levels as barley is very susceptible to infection.

Introduction

Crown rot caused predominantly by the fungus *Fusarium pseudograminearum (Fp)*, is a major disease of wheat and barley crops in the northern grains region (NGR) of Australia, and is estimated to cost growers around $97m annually (Murray and Brennan 2009, 2010).The NSW Department of Primary Industries has pioneered the evaluation of relative yield responses of bread wheat, durum and barley varieties to crown rot in the NGR since 2004, using an inoculated versus uninoculated trial design. In a preliminary study conducted in the NGR, Daniel and Simpfendorfer (2008) observed that the average yield loss from crown rot was 20% in barley (4 varieties), 25% in bread wheat (5 varieties) and 58% in durum (EGA Bellaroi). The aim of this paper was to compare the relative benefit of growing barley or wheat in the presence of crown rot infection, based on data collected from 20 replicated field trials conducted between 2009 and 2014.

Key words

Yield benefit, inoculum load, resistance, tolerance, crown rot, variety.

Method

Between 2009 and 2014, 20 replicated small plot field trials that included the bread wheat variety EGA Gregory, a widely grown cultivar across the NGR, and the dominant malting barley variety Commander, were conducted by NSW DPI. All trials were replicated, and had uninoculated vs. inoculated (2 g inoculum/m row) treatments at sowing using sterilised durum grain colonised by five isolates of *Fp* as described by Dodman and Wildermuth (1987), with five trial sets including a sowing date component. If the interaction of sowing date was significant ($P < 0.05$) data from both dates was presented, if the effect of sowing time was not significant (ns) the average yield result across both planting times is presented. In total this provided 23 comparisons between EGA Gregory and Commander across seasons. As the focus is in the relative performance of barley vs. wheat in the presence of *Fp* infection, only yield results from treatments inoculated with *Fp* are presented. Consequently, this is a comparison across sites and years under high crown rot pressure. The emphasis being on the actual yield achieved under high *Fp* infection levels, rather than percentage yield loss from crown rot, given that yield is a main determinant of profitability for growers.

Replicated trials were also conducted at Tamworth and Garah in 2014 where a range of barley and wheat varieties were evaluated for their relative yield in the presence of high levels of *Fp* infection using an

inoculated vs. uninoculated trial design. Data on the relative yield of wheat and barley varieties only in the presence of crown rot is presented.

Results

In 13 of 23 comparisons (57%) Commander provided a yield benefit over growing EGA Gregory (range +0.28 to +2.20 t/ha; avg. +0.95 t/ha) (Table 1). In 7 of 23 comparisons (30%) the difference in yield between Commander and EGA Gregory was not significant (ns). In three comparisons (13%) Commander was actually significantly lower yielding than EGA Gregory (range -0.33 to -0.77 t/ha, avg. -0.48 t/ha). In 2011 at both sites, mild conditions in terms of temperature and adequate soil moisture limited the expression of crown rot with no significant yield difference between inoculated and uninoculated treatments. In all other trials seasonal conditions favoured varying but significant levels of crown rot expression.

Table 1. Yield of barley cv. Commander compared to wheat cv. EGA Gregory in NSW DPI trials inoculated with *Fp* from 2009-2014

Year	Location	Sowing date	Commander (t/ha)	EGA Gregory (t/ha)	Yield Commander vs Gregory
2009	Coonamble	24 June	3.64	3.12	+0.52
	Tamworth	8 July	4.93	4.06	+0.87
2011	Mungindi	10 May	3.98	4.35	-0.37
		2 June	4.13	4.23	ns
	Coonamble	20 May	4.35	4.71	ns
		22 June	3.09	3.37	ns
2012	Walgett	30 Apr/28 May	6.20	4.00	+2.20
2013	Rowena	30 May	1.81	1.44	+0.37
	Garah	1 May	3.09	2.21	+0.88
		31 May	2.58	2.23	+0.35
2014	Tamworth	20 May/10 June	3.89	2.44	+1.45
	Garah	2 May/12 June	1.17	0.89	+0.28
	Narrabri	15 May	5.62	5.42	ns
	Terry Hie Hie	29 May	1.66	1.99	-0.33
	Spring Ridge	14 May	4.75	4.17	+0.58
	Bithramere	5 June	3.25	2.40	+0.85
	Gilgandra	16 May	5.39	4.12	+1.27
	Coonamble	21 May	5.05	4.82	ns
	Mungindi	16 May	0.77	0.65	ns
	Macalister, Qld	25 May	1.48	2.22	-0.74
	Westmar, Qld	15 May	2.03	1.72	ns
	Trangie	15 May	2.87	1.39	+1.48
	Tamworth	29 May	4.30	3.10	+1.20

Barley is generally considered more tolerant of crown rot (reduced yield impact) than bread wheat (Liu *et al.* 2012) as it tends to escape severe evaporative stress, which exacerbates expression, by maturing earlier. However, as the two sowing times at Garah in 2013 highlighted, this escape mechanism is dependant on sowing time with all four barley varieties in the trial (including Commander) suffering a much higher percentage yield loss from crown rot on the later sowing time (20-30%) relative to the earlier timing (6-11%) (data not shown). Barley is very susceptible to infection by the crown rot fungus and if sown later in its planting window will be filling grain under adverse conditions which may lead to significant yield loss from crown rot. Despite this, Commander is still likely to be higher yielding than EGA Gregory, as can be seen from the trial results for Coonamble 2009, Tamworth 2009 and 2014, and Bithramere in 2014 (Table 1).

Recent research conducted across 11 sites in 2013 and 12 sites in 2014 has highlighted that some of the more recently released bread wheat varieties produced higher yield in the presence of crown rot infection than the widely grown, but more susceptible variety, EGA Gregory. Data on the relative yield of barley varieties in the presence of crown rot is however, more limited. Replicated trials were conducted at Tamworth and Garah

in 2014 where a range of barley and wheat varieties were evaluated for their relative yield in the presence of high levels of crown rot infection. The impact of crown rot on yield was determined through the comparison of yield between plots either inoculated or uninoculated with *Fp* at sowing.

Trial results from Tamworth in 2014, found that *Fp* infection caused yield losses in the barley varieties ranging from 10% in La Trobe up to 29% in Oxford. In the bread wheat varieties yield loss ranged from 14% in Spitfire up to 23% in EGA Gregory. There were however, low to moderate background levels of crown rot across the site which potentially reduced the differences in yield loss. Hence, only the actual yields of each variety measured in the inoculated *Fp* treatment (high infection level) are presented (Figure 1).

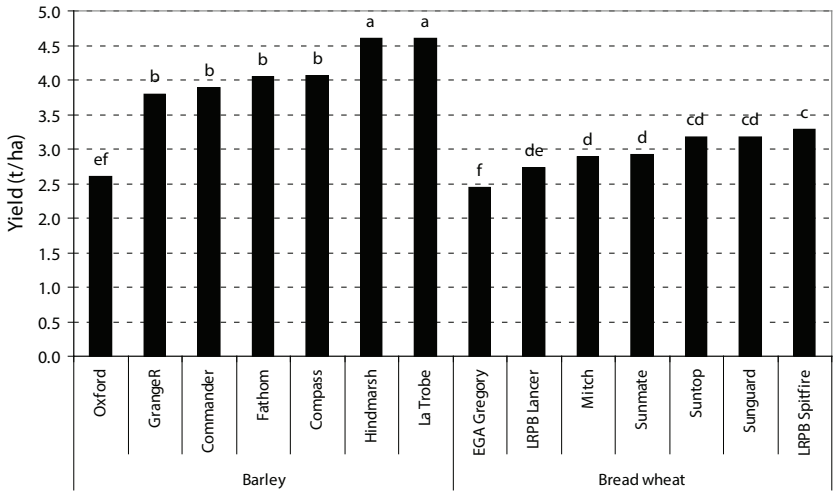

Figure 1. Yield of seven barley and seven bread wheat varieties in the presence of high crown rot infection – Tamworth 2014 (Values are the average of 20 May and 10 June sowing dates; bars followed by the same letter are not significantly (P<0.05) different).

With the exception of Oxford, all barley varieties were higher yielding than EGA Gregory in the presence of high levels of crown rot infection (Figure 1). The reduced biomass barley plant types, Hindmarsh and La Trobe produced higher yield than the other barley varieties being 0.71 t/ha and 0.72 t/ha higher yielding than Commander, respectively. All of the newer wheat varieties were higher yielding than EGA Gregory in the presence of high levels of *Fp* infection. Suntop (0.73 t/ha), Sunguard (0.74 t/ha) and LRPB Spitfire (0.85 t/ha) provided the greatest yield advantage over EGA Gregory (Figure 1). However, even the best bread wheat variety LRPB Spitfire was between 0.51 to 1.32 t/ha lower yielding than all of the barley varieties, with the exception of Oxford.

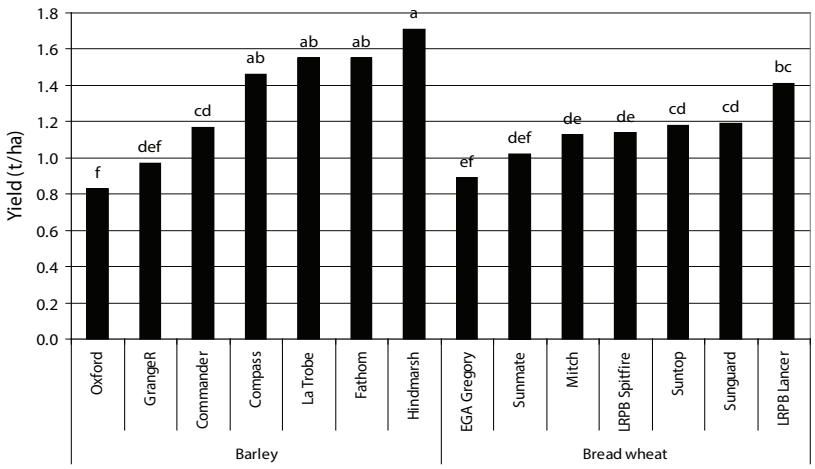

Figure 2. Yield of seven barley and seven bread wheat varieties in the presence of high *Fp* – Garah 2014. (Values are the average of 2 May and 12 June sowing dates; bars followed by the same letter are not significantly (P<0.05) different)

Although Garah was a considerably lower yielding site than Tamworth, encouragingly, the trends in varietal yield performance in the presence of crown rot were fairly consistent with Tamworth. *Fp* infection caused yield loss in the barley varieties ranging from 17% in Hindmarsh up to 31% in GrangeR. In the bread wheat varieties yield loss ranged from nil in LRPB Lancer up to 40% in EGA Gregory. Actual yield of each variety measured in the inoculated *Fp* treatment (high infection level) is presented below (Figure 2).

With the exception of Oxford and GrangeR, all barley varieties were higher yielding than EGA Gregory in the presence of high levels of crown rot infection with Compass (0.29 t/ha), La Trobe (0.38 t/ha), Fathom (0.38 t/ha) and Hindmarsh (0.54 t/ha) all providing significant yield benefits (Figure 2).The best barley variety Hindmarsh was 0.30 t/ha higher yielding than the best bread wheat variety LRPB Lancer (Figure 2).

Conclusions

Barley tends to yield better in the presence of crown rot infection due to its earlier maturity relative to bread wheat, providing an escape mechanism which reduces its exposure to evaporative stress during the critical grain filling stage. This is often referred to as tolerance. To some extent this may also be why the barley variety Oxford, which has a longer maturity, does not yield as well as other barley varieties in the presence of crown rot infection. The tolerance mechanism is lost through the delayed maturity. It is critical that growers do not continue to confuse tolerance with resistance when considering crown rot. Barley is likely to provide a yield advantage over wheat in the presence of high crown rot infection due to better tolerance to this disease. Importantly however, barley will not reduce inoculum levels for subsequent crops as it does not have improved resistance to crown rot infection compared to bread wheat (Liu *et al.* 2012).

If forced into planting a cereal crop in a high crown rot risk situation some barley varieties may provide a yield advantage over bread wheat in a given season, due to better disease tolerance. Importantly, some of the newer bread wheat varieties do appear to be closing this gap to some extent. Nevertheless, a key message is that this decision is only potentially maximising profit in the current season. Growing barley over bread wheat will not assist with the reduction of crown rot inoculum levels as barley is very susceptible to infection. Significant yield loss is still occurring in the best of the barley and bread wheat varieties in the presence of high crown rot infection. Crop and variety choice is therefore not the sole solution to crown rot but rather just one element of an integrated management strategy to limit losses from this disease.

Acknowledgements

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Managing viral diseases in chickpeas through agronomic practices

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Abstract
Chickpea and other winter pulse crops are susceptible to many plant viruses. Virus disease outbreaks in chickpeas are episodic and difficult to predict and plants that become infected with a virus invariably die. All are spread by flying insect vectors. However, neither seed applied insecticides nor regular foliar applied insecticides were effective in field trials conducted in three seasons in the high virus risk region of the Liverpool Plains. All current commercial desi and kabuli varieties grown in northern NSW are susceptible to the main viruses.

The only strategies to reduce the risk of viruses in chickpea are agronomic. Experiments in 2012 and 2013 examined the impact of crop density, row spacing and cereal residue on the incidence of virus in chickpea. In both years, very low plant density (5 plants/m^2) exhibited the highest incidence of virus symptoms (62% in 2012 and 12% in 2013) with the incidence declining in a curvilinear fashion as plant densities increased (30 plant/m^2, 6% in 2012 and 2% in 2013). Row spacing, at a fixed plant density (30 plant/m^2), suggested that 80 cm wide rows had a lower incidence of virus (3.5 plants/20m^2) compared with 40 cm rows (9 plants/20m^2). Where cereal residue is retained, inter-row sowing into standing residue resulted in a lower incidence of virus infected plants (15 plants/20m^2) compared to flattened residue (27 plants/20m^2). The effect of agronomic practices, under zero tillage, to reduce virus incidence in chickpea is discussed.

Key words
Plant population, direct seeding, wheat, stubble

Introduction
There are over 14 species of virus that naturally infect chickpeas. These viruses are spread by airborne insects with aphids being the predominant vector. The aphids that fly in to crops do not stay long and do not normally colonise plants. Typical virus symptoms are bunching, reddening, yellowing, death of shoot tips and early death of whole plants. However, it should be remembered that none of these are diagnostic for virus. The occurrence of virus in chickpeas is episodic and changes dramatically from season to season and location. Clovers, medics, canola/mustard, weeds, and other pulses can host viruses that infect chickpea.

The best control strategies to reduce risk of viruses are agronomic. These include; retaining cereal stubble, sowing on time, establishing a uniform closed canopy and controlling weeds (Schwinghamer et al 2009). Seed and foliar insecticides are not recommended for chickpea viruses.

Methods
Variety x plant density experiments
In 2012 and 2013 experiments were conducted to examine the effect of variety and plant density on chickpea viruses. This consisted of five varieties (PBA Boundary, Cica-912, PBA HatTrick, Genesis™ 090, Kyabra) by six plant densities (5, 10, 15, 20, 30 and 45 plants/m^2) by three replicates at a fixed row spacing of 40cm. During 2012 experimental sites were at Coonamble and Tamworth Agricultural Institute (TAI). In 2013 the number of sites was expanded to eight; North Star, Moree, Edgeroi, Burren Junction, Coonamble, TAI, Pine Ridge and Trangie. Only TAI and Pine Ridge were infected with virus in 2012 and 2013 and 2013, respectively.

Row spacing and stubble management experiments
In 2013 two experiments were conducted at TAI to look at the effect of row spacing and stubble management. The row spacing experiment consisted of ground engaging tool (disc and tyne) by row spacing (40cm and 80cm) by row placement (between or on row sowing) by three replicates. The stubble

management experiment compared standing versus flat (slashed) wheat stubble (six replicates) at a fixed row spacing (40 cm) on incidence of plants with virus symptoms. Chickpea, cultivar PBA HatTrick , was sown at 30 plants/m^2 in both experiments.

Virus species in Pine Ridge and Tamworth experiments
Chickpea plants with symptoms of virus infection were sampled for virus testing by Tissue Blot Immuno Assay (TBIA). At each sampling time, 15 symptomatic plants were collected and tested for Alfalfa mosaic virus (AMV), Cucumber mosaic virus (CMV) and Beet western yellows virus (BWYV). At Pine Ridge, 15 symptomatic plants were also tested from the surrounding crop of Almaz chickpeas. In addition 15 asymptomatic (healthy, turgid, vigorous, green plants) were also tested from each trial and the Almaz crop. By far the most common virus was BWYV, accounting for 65 – 94% (mean 83%) of symptomatic plants; 12% of symptomatic plants were positive for AMV; CMV was not detected in any symptomatic plants; only one (out of 105) plant was co-infected with BWYV and AMV. None of the 45 asymptomatic plants tested positive to any of the three viruses.

The data were subjected to analysis of variance and comparison between treatment means was performed by using the minimum significant difference (at $P \leq 0.05$) using S-Plus software (Version 6.1).

Discussion
Plant density and incidence of plants with virus symptoms
In 2012 at TAI, varieties showed no significant difference in terms of plants with virus symptoms (%) but there was a highly significant effect with plant density (Figure 1). The highest incidence of symptomatic plants occurred at the lowest plant density (5 plants/m^2). Incidence declined in a curvilinear fashion as plant densities increased. However, there was no significant difference in the incidence of plants with virus symptoms for 20, 30 and 45 plant/m^2 densities.

In 2013 only two of the eight sites showed virus symptoms, one at Pine Ridge in the virus prone region of the Liverpool Plains (van Leur et al 2003) and the other at TAI. As occurred in 2012, incidence of symptomatic plants was greatest at the lowest density (5 plants/m^2) at both sites and declined as plant densities increased. However, there was no significant difference in the proportion of plants with virus symptoms at 20, 30 and 45 plants/m^2 (Figure 2).

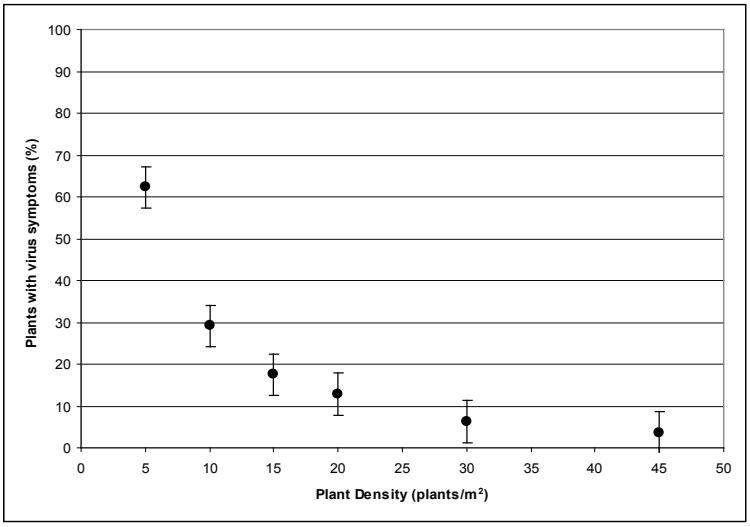

Figure 1 Effect of plant density on incidence of chickpea plants with virus symptoms at TAI, 2012.

Row spacing and incidence of plants with virus symptoms
Row spacing had a significant effect on incidence of plants with virus symptoms in a 2013 trial at TAI. On 11 October 2013, there were more than twice as many symptomatic plants/m^2 in plots with 40cm rows compared to those with 80cm rows (Figure 3). Both row configurations were sown at 30 plants/m^2 so plant density per unit area cannot account for the difference. Rather, plant density within each row appears to be responsible (12 plants/m row @ 40cm and 24 plants/m row @ 80cm).

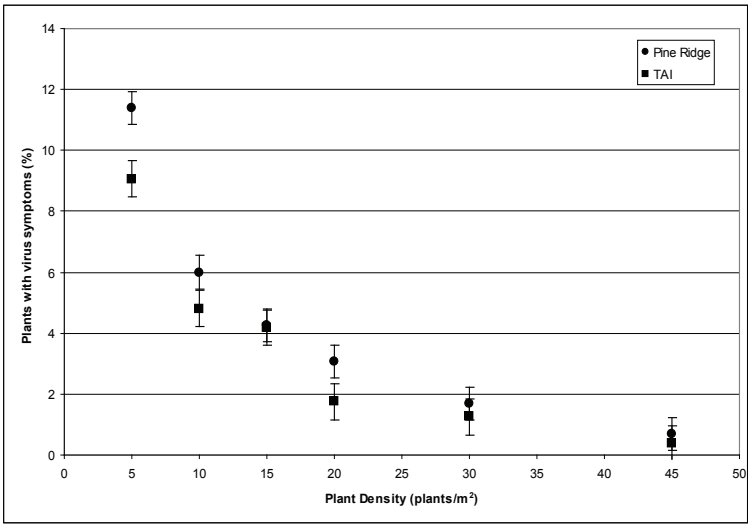

Figure 2 Effect of plant density on incidence of chickpea plants with virus symptoms at Pine Ridge and TAI, 2013.

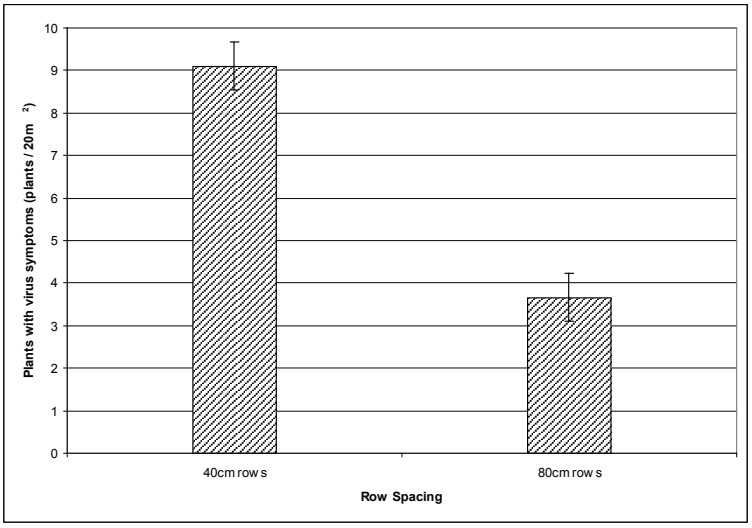

Figure 3 Effect of row spacing on incidence of chickpea plants with virus symptoms at TAI, 2013.

Stubble management and incidence of plants with virus symptoms

An experiment was conducted at TAI in 2013 to compare standing versus flat (slashed) wheat stubble on incidence of plants with virus symptoms. Sown at 40cm spacing with PBA HatTrick® at 30 plants/m^2. The trial was assessed on 16 October. The incidence of plants with virus symptoms was lower (15 plants/20m^2) where the chickpeas were sown between rows of standing wheat stubble compared to flat stubble (27 plants/20m^2, s.e.d.m ± 3.9).

Conclusions

In September/October 2012, viruses were common in chickpea crops throughout north central and northern NSW – almost every crop inspected had some level of virus (Moore *et al*, 2013, van Leur *et al*, 2013). Observations during that period suggested a link between plant density and incidence of virus; in addition, growers and agronomists reported a higher incidence of virus in chickpea crops with thin stands. Experiments conducted in 2012 and again in 2013 showed that very low plant density (5 plants/m^2) exhibited the highest incidence of virus symptoms (62% in 2012 and 12% in 2013) with the incidence declining as plant densities increased (30 plant/m^2, 6% in 2012 and 2% in 2013).

Chickpea yields have been shown to be stable across a range of row spacing up to about 80cm. Wide row chickpea crops sown into standing cereal residue are common place in northern NSW and Qld (Verrell and Jenkins 2013). In 2013 a row spacing experiment showed that the wide row chickpeas (80cm) had a lower incidence of virus compared to narrow rows (40cm) when sown at a fixed density of 30 plants/m^2. This lower incidence is most likely due to the higher intra row plant density at 80cm.

Planting into standing cereal stubble is known to help reduce risk of virus in lupin crops (Jones, 2001). Retaining standing winter or summer cereal is believed to be useful in reducing risk of virus in chickpea crops (Schwinghamer *et al* 2009) although van Leur *et al* (2013) found no relationship between stubble loading and incidence of virus in a quantitative survey of viruses in 2012 chickpea crops on the Liverpool Plains. Experiments in 2013 showed that planting between standing cereal rows reduced the incidence of virus compared to sowing into cereal residue that had been flattened.

At the moment the best way to minimise the impact of virus on chickpea is through the following agronomic practices;

- Sow at the optimal seeding rate - irrespective of sowing date, to ensure early canopy closure to reduce aphid attraction to plants.
- Retain standing stubble – this deters aphids from landing on the crop.
- Sow between standing cereal rows - use precision agriculture techniques to sow between the stubble rows. This assists generating a uniform crop canopy which makes the crop less attractive to aphids.

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Fusarium crown rot of wheat - impact on plant available soil water usage

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Abstract

Expression of crown rot, caused by *Fusarium pseudograminearum*, is related to moisture and or evaporative stress during grain filling. The impact of the disease on plant soil water use is however, not well understood so we investigated it in the durum variety Caparoi at Walgett in 2012 and both Garah and Rowena in 2013. Neutron probe access tubes were installed in replicated inoculated and uninoculated plots to 1.8 m in each season. Soil moisture was measured in depth intervals at GS30, GS39, GS61, GS80 and GS92. Stress occurred relatively late at Walgett in 2012 due in part to a full starting moisture profile and average early season rainfall and temperatures. Stress occurred earlier at both sites in 2013 with infection impacting on soil water use from GS39 onwards. Crown rot infection prevented extraction of a total of 24 mm of PAW at Garah and 49 mm of PAW at Rowena by harvest. Crown rot infection reduced yield from 3.78 t/ha down to 3.11 t/ha (17.8% yield loss) at Walgett in 2012 with screenings increasing from 6.4% up to 13.2%. At Garah in 2013, crown rot reduced yield by 55.3% (2.20 t/ha down to 0.98 t/ha) with hectolitre weight decreasing from 82.6 kg/hL to 75.5 kg/hL. At Rowena in 2013, crown rot reduced yield by 64.3% (3.32 t/ha down to 1.18 t/ha) with screenings rising from 6.6% up to 19.5%. Crown rot restricts the plants ability to extract PAW which significantly impacts on yield and grain quality.

Key words

Plant available water (PAW), durum, crown rot, yield, grain quality.

Introduction

Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum (Fp)*, is considered the most important disease of durum wheat (*Triticum turgidum*) in the northern grains region of Australia (Kneipp 2008), and is also a major constraint to both bread wheat and barley production. Yield losses attributed to crown rot can exceed 60% in susceptible crops such as durum wheat particularly if moisture stress occurs during grain filling (Daniel and Simpfendorfer 2008). Crown rot infection is characterised by a honey-brown discolouration at the base of infected tillers. It is believed to be initiated by moisture stress and results in the proliferation of hyphal growth in the base of infected tillers, restricting water movement through the plant. Yield loss is related to the expression of 'whiteheads' during flowering and grain fill, these prematurely ripened spikes contain either no grain or shrivelled grain depending on the timing of stress relative to crop development. This study investigated the effect of crown rot infection on soil water use in the durum cultivar (*cv*.) Caparoi and its impact on yield and grain quality parameters.

Method

Trials were conducted at a total of three sites in northern NSW over two years, these included Walgett in 2012, and Garah and Rowena in 2013. All trials were replicated, and had uninoculated versus inoculated (2 g inoculum/m row) treatments at sowing using sterilised durum grain colonised by five isolates of *Fp* as described by Dodman and Wildermuth (1987). The trial included a bread wheat (*cv.* Spitfire), a durum (*cv.* Caparoi) and a barley variety (*cv.* Commander), planted at 80 or 160 plants/m^2 across three row spacing's of 300, 400 and 500 mm. Neutron probe access tubes were installed in all replicated inoculated and uninoculated plots to 1.8 m in each season. Soil moisture was measured in 0-30, 30-60, 60-90, 90-120 and 120-150 cm depth intervals at stem elongation (~GS30), flag leaf fully emerged (~GS39), flowering (~GS61), grain filling (~GS80) and physiological maturity (~GS92). The upper and lower soil water limits were characterised at each location through a 'wet-up' and 'rain exclusion' site adjacent to the trial area. This data was used to determine the Plant Available Water (PAW) at incremental depths down the soil profile for each plot at the different growth stages. Only the total average soil water usage, yield and grain quality parameters for the durum variety Caparoi with plus or minus added *Fp* are presented in this paper to simplify interpretation. The trial data was analysed as a regular grid spatial mixed model in Genstat 17th edition.

Results

In 2012 at Walgett, due to a good starting soil moisture profile, average March to September rainfall, and generally average to below average in crop monthly maximum temperatures, moisture stress occurred relatively late in the season. Due to the late onset of moisture stress, there was no significant difference in water extraction in terms of PAW remaining in the profile of infected versus uninfected durum plots averaged across all treatments (Figure 2a). The presence of crown rot infection did not cause a significant *(P*<0.05*)* yield loss in barley and only a slight reduction of ~3.7% for bread wheat, when averaged across all treatments (data not shown). In contrast, the durum *cv.* Caparoi experienced a yield loss of 17.8% in the presence of *Fp* infection with yield decreasing from 3.78 t/ha to 3.11 t/ha (Figure 1a). Importantly, screenings (grain below the 2.0 mm screen) increased from 6.4% to 13.2% (Table 1), which would have resulted in a downgrading from *ADR3* to Feed grade and therefore both a yield and grain quality penalty was associated with crown rot infection even in a season with relatively moderate and late season moisture/temperature stress.

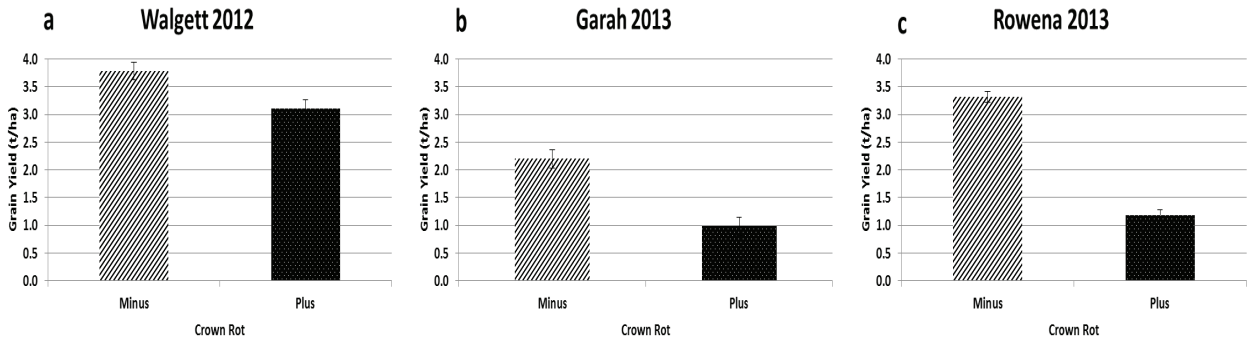

Figure 1. Grain yield (t/ha) for the durum wheat *cv.* Caparoi plus and minus *Fp* infection, average across row spacing and plant populations at Walgett in 2012 (a), Garah in 2013 (b), and Rowena (c) in 2013. Bars represent lsd (*P*=0.05).

In contrast to the 2012 Walgett trial, moisture stress occurred in early August (~GS39) at both Garah (Figure 2b) and Rowena (Figure 2c) in 2013. Monthly rainfall at Garah and Rowena was below average in July, August and October 2013 with the mean maximum temperatures for July to October above average and or equivalent to the long-term highest mean monthly maximum temperatures. The difference in water extraction at Garah in terms of PAW remaining in the soil profile of *Fp* infected versus uninoculated plots was 10.3 mm at GS39 increasing to 24 mm at physiological maturity ~GS92 (Figure 2b). At Rowena the difference in unextracted PAW between plus and minus *Fp* infected plots was 23 mm at GS39, increasing to 49 mm at physiological maturity. These results demonstrate the potential for crown rot infection to restrict the ability of crops to extract PAW, which has a significant impact on grain yield and quality.

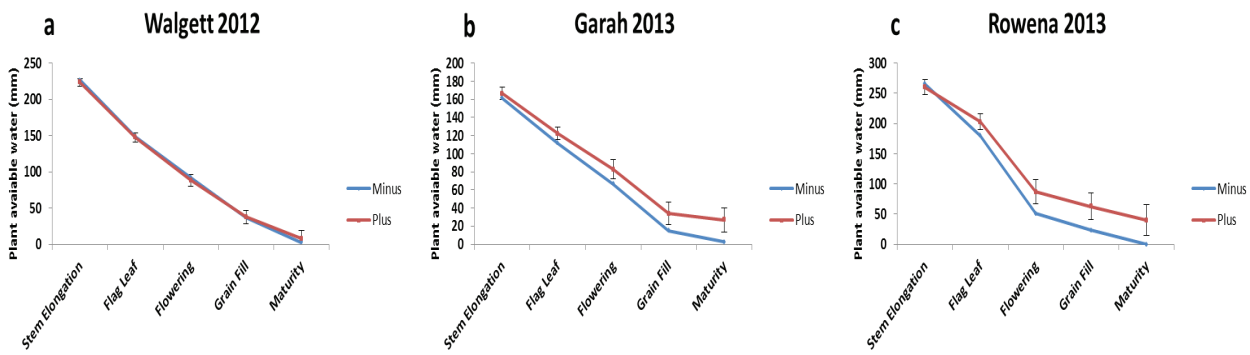

Figure 2. Impact of crown rot (plus and minus *Fp* infection) on soil water use of the durum wheat *cv.* Caparoi (0-150 cm) - Walgett 2012 (a), Garah 2013 (b), Rowena 2013 (c). Bars represent lsd (*P*=0.05).

Crown rot infection reduced yield by 55.3% (2.20 t/ha down to 0.98 t/ha) at Garah, and by 64.3% (3.32 t/ha down to 1.18 t/ha) at Rowena in 2013 (Figure 1b and c). Apart from grain yield, crown rot also impacted on grain quality parameters. Test weights at Garah decreased by 7.11 kg/hL, from 82.61 for uninfected plots to 75.54 kg/hL in *Fp* infected plots (Table 1). Similarly, screenings increased from 6.62% to 19.54% for *Fp*

infected plots at Rowena with Thousand Grain Weight (TWG) also decreasing in the presence of *Fp* infection (Table 1). It was also noted that grain protein concentration decreased at both Garah and Rowena in *Fp* infected treatments indicating that crown rot infection also appears to impact on the extraction, translocation and/or redistribution of nitrogen (N) within the plant.

Table 1. Grain quality parameters measured at each location for the durum *cv.* Caparoi plus and minus *Fp* infection.

Location	Grain Quality	Minus	Plus	lsd (*P*=0.05)
Walgett 2012	Protein (%)	11.76	12.65	0.27
	Screening (%)	6.36	13.21	0.16
	Test weight (kg/hL)	83.25	78.62	0.48
	TGW (g)	32.77	27.49	0.76
Garah 2013	Protein (%)	13.86	13.55	0.23
	Test weight (kg/hL)	82.61	75.54	1.13
Rowena 2013	Protein (%)	14.11	12.81	0.19
	Screening (%)	6.62	19.54	1.23
	TGW (g)	28.76	23.66	1.11

Conclusions

Yield loss associated with crown rot infection, is largely related to the expression of whiteheads, which is influenced by moisture and/or temperature stress during flowering and grain filling (Chakraborty *et al.* 2006). Crown rot infection was shown to restrict the plants ability to extract PAW, its impact on grain yield and quality, being dependant on the timing of stress relative to crop development. Results showed that even with only relatively moderate late seasonal moisture/temperature stress, such as experienced at Walgett in 2012, that the durum *cv.* Caparoi still experienced a yield loss of 17.8% in the presence of *Fp* infection, with screening levels also increasing from 6.36% to 13.21%. At Garah and Rowena, with stress occurring earlier in the season from GS39 onwards the presence of *Fp* infection resulted in a significant decrease in the extraction of PAW. This resulted in significant reductions in both yield and grain quality. Yield decreased by 55.3% at Garah and by 64.3% at Rowena, grain quality parameters (screenings/test weight) were also impacted, resulting in quality downgrades. These results reinforce the susceptibility of durum to crown rot infection and highlight the need to avoid planting, where there is an increased potential risk of infection and or increased likelihood of early onset of moisture stress particularly during anthesis and grain fill.

Acknowledgements

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Summer production of alternative species in comparison to perennial ryegrass and white clover for high input pasture systems

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Abstract
The increase in irrigable land in the Midlands region of Tasmania presents an opportunity to increase animal production, whether it is lamb, dairy or beef. However, challenges including low rainfall (<650 mm annual average rainfall, high amounts of irrigation are required to maintain soil moisture), high summer temperatures (days >27°C) and duplex winter wet soils in this region put into question the suitability of the traditional intensive pasture base of perennial ryegrass *Lolium perenne* and white clover *Trifolium repens*. This study evaluated the performance of alternative grass and legume species under high input management for diversifying the feedbase in this region. The experiment was sown with 29 pasture treatments consisting of mixed swards and monocultures of 5 grass species (perennial ryegrass, tall fescue *Festuca arundinacea*, coloured brome *Bromus coloratus*, cocksfoot *Dactylis glomerata* and phalaris *Phalaris hybrid*) and 4 legume species (white clover, red clover *Trifolium pratense*, strawberry clover *Trifolium fragiferum* and Caucasian clover *Trifolium ambiguum*). The experiment was fully irrigated and nitrogen was applied at 40 kg N/ha following each harvest event. Dry matter (DM) yield was assessed at six defoliation events between November 2014 and April 2015. Perennial ryegrass and coloured brome were the best performed grasses, with coloured brome only significantly ($P<0.05$) lower than perennial ryegrass on one of the six harvest dates. The addition of the 4 clover cultivars to each of the 5 grass swards made no significant difference to yield except where white clover was in combination with phalaris. This study highlights the potential of coloured brome as an alternative to perennial ryegrass in high input systems although its tolerance of waterlogging, typical in the Midlands region requires further evaluation.

Keywords
Coloured brome, tall fescue, cocksfoot, phalaris, red clover, DM yield

Introduction
Recent and ongoing irrigation expansion in the Midlands region of Tasmania has led to an increase in intensive grazing systems. In an area once most suited to wool and cereal production, high input pastures for finishing lambs and dairy farming are now seen as economically viable enterprises. These intensive grazing systems will require greater flexibility in their feedbase for a few reasons. As rainfall is more variable a diverse feedbase containing multiple species may help to fill feed gaps and withstand prolonged periods of moisture stress where irrigation needs to be prioritised. In addition, the shallow duplex soil type provide challenges with pugging and pasture growth in waterlogged areas than in traditional dairy regions. The productivity and nutritive value of alternative grasses and legumes under irrigation in these areas is unknown. There are some existing and novel species/cultivars available that could provide good production while adding flexibility to the grazing resource. These include: summer active cocksfoot cv. Megatas, coloured brome cv. Exceltas, tall fescue cv. Quantum II MaxP, Caucasian clover cv. Kuratas, strawberry clover cv. Palestine and stoloniferous red clover cv. Rubitas. Of particular interest is the seasonal production of the new cultivars developed by the Tasmanian Institute of Agriculture (TIA), coloured brome and stoloniferous red clover under input irrigation and high N input systems, as these two cultivars have not been evaluated under such conditions previously. Studies by Hall and Hurst (2012) and presented by Hackney *et al*. (2007) indicated that coloured brome cv. Exceltas could match and even surpass the DM production of perennial ryegrasses grown under dryland conditions. This study evaluated the seasonal production of alternative grasses and legumes in monoculture and mixed swards in comparison to perennial ryegrass/white clover under irrigation and high nitrogen input in Midlands region of Tasmania.

Methods

The trial site was established in 2014 at Cressy (41° 43'S, 147° 03'E) in Northern Tasmania where the mean annual rainfall is 628 mm and the elevation 147 m. The soil is a brown chromosol, and can be described as duplex with a heavy clay subsoil. The trial was sown in April 2014 with an Ojyard cone seeder into a shallow cultivated seed bed, prepared over 12 months from a previously degraded pasture. The experiment was a randomised block design with four replicates with plot sizes 3 m x 1.5 m. Pasture cultivars were sown as both monocultures and in mixed swards, using all the grass/clover combinations. Sowing rate for each cultivar was dependant on seed size and if sown as a monoculture or in a mix (Table 1). Growing season rainfall (November 2014 – April 2015) was 152.5 mm plus an additional 665 mm of irrigation applied to make the study fully irrigated. Plots received 40 kg/ha of nitrogen following each harvest. Maintenance levels of phosphorus and potassium were applied at 42 kg P/ha and 169 kg K/ha respectively. Weeds and pests were controlled as required, although in some plots volunteer grass, legume and broadleaf weeds became difficult to manage as a result of slow or poor establishment of the sown species.

Plots were cut twice during establishment in early spring, prior to dry matter (DM) evaluation at 6 harvest events between November 2014 and April 2015. Defoliation interval was between 26 and 34 days depending on growth rates. Dry matter (DM) yield was assessed across all pasture treatment plots by quadrat cuts (2 per plot) when the perennial ryegrass plots had reached the three leaf regrowth stage. Plants were defoliated to 5cm using hand shears and following collection the residual plot area was mown to 5cm. Pasture samples were botanically separated into the individual cultivars planted, with weed and non-sown species removed. Samples were oven dried at 56 °C for 48 hours to determine DM yield. The yield data were analysed assuming a randomised block design using Proc Mixed software of the SAS System version 9.3 [SAS Institute Inc. 2014. SAS/STAT ® 13.2 User's Guide. Cary, NC: SAS Institute Inc]. Each harvest time was analysed separately. Differences and associated 95% confidence intervals of predicted means were calculated using Proc Plm software of the SAS System version 9.3 [same ref as above] and P values adjusted for multiplicity using simulation. The half-width of the confidence interval was used to identify homogeneous pairs of predicted means (Westfall *et al*., 1999).

Table 1: Sowing rates (kg/ha) of pasture cultivars in monoculture (mono) and mixed swards

Grasses	Mono	Mixed	*Legumes*	Mono	Mixed
Perennial ryegrass *cv. Base*	15	12	White clover *cv. Bounty*	6	3
Coloured brome *cv. Exceltas*	20	12	Red clover *cv. Rubitas*	6	4
Cocksfoot *cv. Megatas*	5	3	Strawberry clover *cv. Palestine*	6	3
Tall fescue *cv. Quantum II MaxP*	12	10	Caucasian clover *cv. Kuratas*	6	4
Phalaris *cv. Advanced AT*	5	3			

Results

There were significant (P<0.05) differences between the yields (t DM/ha) of the 5 perennial grasses sown in monoculture at different harvest times (Table 2). Perennial ryegrass was the best performed grass, yielding equal to or significantly higher than all other grasses at each harvest time. Coloured brome also performed well and only differed from perennial ryegrass at the January 2015 cut. Cocksfoot and tall fescue yielded significantly less than perennial ryegrass at the January 2015 cut. Except for the first cut in November 2014, the yield of phalaris was significantly (P<0.05) lower than perennial ryegrass and coloured brome at each harvest thereafter. White clover was the best performed legume in monoculture, significantly (P<0.05) out yielding other clovers except red clover on 3 harvest dates and strawberry clover in November 2014. Caucasian clover performed poorly throughout. The inclusion of the white clover in the phalaris mixed swards had a positive effect of DM yields, significantly higher (P<0.05) in the later cuts (Table 2). However, there appeared to be no significant (P<0.05) response in yields with the inclusion of white clover, or any other clover in mixed swards consisting of perennial ryegrass, coloured brome, cocksfoot or tall fescue.

Discussion

Perennial ryegrass was the best performed perennial grass in this study and is the foundation of the majority of intensive pastures in Tasmania. However, the production of coloured brome was quite similar and was only significantly less at one of the harvest dates. The suggestion of the brome species as an alternative to perennial ryegrass was raised by Slack *et al*. (2001) who showed prairie grass *Bromus willdenowii*

outperformed perennial ryegrass under high temperatures providing the defoliation interval was extended. High daytime temperatures during summer are a characteristic of the Midlands region, compared with other areas of Tasmania. Many of the lower lying soils in the Midlands region are duplex and prone to waterlogging. Bromes including grazing brome *Bromus stamineus* cv. Grasslands Gala have poor tolerance of waterlogged soils (Stewart, 1992; Stewart 1996). The potential of coloured brome on such soils, although listed by Hall and Hurst (2013) as moderate, has yet to be fully evaluated. On free draining soils or in areas where summer irrigation may not always be available, coloured brome provides an animal friendly alternative to perennial ryegrass as suggested by Hall and Hurst (2012).

Table 2: Predicted means of dry matter yield (t DM/ha) of mixed and pure pasture swards across harvest dates.

Pasture treatments	**5/11/14**	**9/12/14**	**7/1/15**	**5/2/15**	**5/3/15**	**31/3/15**	**TOTAL**
Growing days	28	34	29	29	29	26	
Grass comparisons							
Phalaris	1829[a]	1192[b]	1022[c]	515[b]	649[b]	647[b]	5854
Perennial ryegrass	2673[a]	2250[a]	2856[a]	2215[a]	2552[a]	1644[a]	14190
Coloured brome	2604[a]	2408[a]	1883[b]	2220[a]	2783[a]	1466[a]	13364
Cocksfoot	2286[a]	1726[ab]	1977[b]	1888[a]	2664[a]	1334[ab]	11874
Tall fescue	2133[a]	1627[ab]	1667[bc]	1986[a]	2440[a]	1436[a]	11288
Clover comparisons							
White clover	1689[a]	1406[a]	1784[a]	1300[a]	1878[a]	1020[a]	9077
Caucasian clover	86[b]	38[b]	120[c]	49[c]	111[c]	87[b]	490
Strawberry clover	1669[a]	289[b]	363[bc]	326[bc]	546[bc]	257[b]	3449
Red clover	1601[a]	594[b]	937[b]	887[ab]	965[b]	497[ab]	5480
Phalaris comparisons							
Phalaris	1829[a]	1192[a]	1022[a]	515[ab]	649[bc]	647[b]	5854
Phalaris/White clover	2222[a]	1014[a]	1129[a]	1038[a]	1980[a]	1494[a]	8876
Phalaris/Caucasian clover	1921[a]	1216[a]	644[a]	192[b]	262[c]	154[b]	4383
Phalaris/Strawberry clover	1891[a]	812[a]	742[a]	362[ab]	674[bc]	437[b]	4918
Phalaris/Red clover	2315[a]	957[a]	888[a]	710[ab]	1144[b]	734[b]	6747
Perennial ryegrass comparisons							
Perennial ryegrass	2673[a]	2250[a]	2856[a]	2215[a]	2552[a]	1644[a]	14190
Perennial ryegrass/White clover	2883[a]	2127[a]	2687[a]	1966[a]	2448[a]	1590[a]	13700
Perennial ryegrass/Caucasian clover	2602[a]	2247[a]	2789[a]	2291[a]	2536[a]	1356[a]	13821
Perennial ryegrass/Strawberry clover	2691[a]	2289[a]	2764[a]	2041[a]	2539[a]	1569[a]	13892
Perennial ryegrass/Red clover	2836[a]	2319[a]	2479[a]	2093[a]	2801[a]	1707[a]	14235
Coloured brome comparisons							
Coloured brome	2604[a]	2408[a]	1883[a]	2220[a]	2783[a]	1466[a]	13364
Coloured brome/White clover	3058[a]	2428[a]	1852[a]	1985[a]	2782[a]	1871[a]	13977
Coloured brome/Caucasian clover	2593[a]	2301[a]	1809[a]	2066[a]	2662[a]	1450[a]	12873
Coloured brome/Strawberry clover	3122[a]	2422[a]	2084[a]	2028[a]	2712[a]	1637[a]	14005
Coloured brome/Red clover	3099[a]	2259[a]	1917[a]	1887[a]	2950[a]	1717[a]	13829
Cocksfoot comparisons							
Cocksfoot	2286[a]	1726[a]	1977[a]	1888[a]	2664[a]	1334[a]	11874
Cocksfoot/White clover	2580[a]	1780[a]	2052[a]	2127[a]	2826[a]	1543[a]	12908
Cocksfoot/Caucasian clover	2397[a]	1797[a]	2285[a]	2340[a]	2874[a]	927[a]	12619
Cocksfoot/Strawberry clover	2747[a]	1963[a]	2060[a]	2036[a]	2663[a]	1548[a]	13017
Cocksfoot/Red clover	2096[a]	1753[a]	2069[a]	2069[a]	2815[a]	1345[a]	12146
Tall fescue comparisons							
Tall fescue	2133[a]	1627[a]	1667[a]	1986[a]	2440[a]	1436[a]	11288
Tall fescue/White clover	2781[a]	1945[a]	1917[a]	1980[a]	2760[a]	1646[a]	13028
Tall fescue/Caucasian clover	2395[a]	1725[a]	1719[a]	1768[a]	2561[a]	1464[a]	11631
Tall fescue/Strawberry clover	2181[a]	2002[a]	1951[a]	2209[a]	2693[a]	1628[a]	12664
Tall fescue/Red clover	2431[a]	1971[a]	1937[a]	1703[a]	2544[a]	1422[a]	12008
95% CI half-width	1165	795	724	682	779	748	

Note: 95% CI half-width was estimated using simulation (see text). Letters indicate significant ($P<0.05$) differences between pasture treatments within each group of comparisons.

In this study phalaris produced significantly less than other grass cultivars, particularly from January onwards. This could partially be explained by Advanced AT being a winter active cultivar of phalaris (Culvenor, 2009) with a low level of summer dormancy. The continuation of the current study for the remainder of 2015 will show the seasonal production of phalaris during winter. However, it is unlikely that the annual production phalaris could match perennial ryegrass under these conditions and the full value of this cultivar is under dryland conditions in this region. The semi erect growing nature of this cultivar provided an open canopy for the growth of clovers. This is reflected in the yields of phalaris/white clover being significantly higher than the phalaris monoculture in the latter harvest dates. This was not observed in any of the other grass/legume mixed swards. The grasses quickly became dominant, reaching canopy closure and being very competitive against the clover under the high nitrogen applications. In monoculture, white clover was the highest performing clover, while the sowing time (April) was not favourable for Caucasian clover resulting in very slow establishment and strong competition from broadleaf weeds and grass weeds. Spring sowing Caucasian clover is recommended in this climatic region (Hall and Hurst, 2013).

Conclusion

Results from this study show that perennial ryegrass has confirmed its position as the most productive perennial grass species under a high input irrigation system in a cool temperate environment. However, coloured brome has shown to have the potential to be a viable alternative in this environment. These results reflect a snapshot of each cultivars performance over one summer. The continuation of this study over a much longer period of time will provide a clearer picture of each species full potential. The promising performance of the new species, coloured brome vs perennial ryegrass at this site indicates there is a need to compare these grasses across a wider range of environments, especially those with warmer summers, where the summer growth of perennial ryegrass is compromised by the heat.

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Chicory (*Cichorium intybus* L.) can beat the heat during summer drought in southeast Australian dairying regions

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Abstract
Perennial ryegrass (*Lolium perenne* L.) is the major sown pasture species in southeast Australian dairying regions. Ryegrass is not only intolerant of soil moisture deficits, but heat waves, which increasingly present a challenge to summer home-grown feed production. To address this challenge, a screening experiment was undertaken to identify temperate perennial forage species, better adapted to combined heat wave stress and soil moisture deficits. Responses of ten perennial forages to optimal and heat wave temperature regimes (day/night ambient temperatures of 23/15˚C and 38/26˚C) were evaluated under greenhouse conditions. The effect of moisture availability (optimal watering or no water) and the recovery capacity of plants grown in optimal conditions (day/night ambient temperature regime of 23/16˚C; optimal watering) for 18 d after stress periods ceased, were also examined. Chicory (*Cichorium intybus* L., cv. Grasslands Puna) had a superior tolerance to heat stress and moisture deficit compared with ryegrass cv. Samson. Chicory not only maintained live above-ground tissue after exposure to the combined stress for 18 d, but increased in yield by 46% during the recovery period. In contrast at 12 d, live tissue was not detectable in the ryegrass, with yield measurements indicating plants unable to recover. Results suggest that under dryland conditions, chicory may enable a greater level of home-grown feed production to resume following an extended heat wave, than possible with ryegrass.

Key words
Heatwave, high temperature, water stress, climate change, grazing, dry matter

Introduction

Dairying in temperate southeast (SE) Australia has remained economically viable, despite declining terms of trade. This is due to the competitive advantage of favourable climatic conditions for growing low-cost home-grown feed (Chapman et al, 2011). Heat waves increasingly challenge this advantage, and often coincide with summer soil moisture deficits. Two of the regions' most severe heat waves in the last century have occurred since 2009 (BOM, 2014). During the January 2009 heat wave, daily ambient temperatures (Ta) exceeded 35-40˚C on three or more consecutive days, at locations typical of the key Victorian dairying districts (East Sale, Kerang, and Warrnambool). Heat waves are forecast to increase in frequency, duration, and intensity during the 21st century (Parker et al, 2014). In Tasmania the frequency of heat waves is projected to increase in the Midlands and Derwent Valley (White et al, 2010); two regions currently experiencing expansion in dairying.

Southeast Australian dairy farming systems are particularly vulnerable, due to 60-70% of the dairy cow's diet being derived from perennial ryegrass (*Lolium perenne* L.) (Chapman et al, 2008). Without moisture, stress shoot growth inhibition of ryegrass occurs at an Ta of 35˚C (Mitchell, 1956), with detrimental high temperatures effects exacerbated by soil moisture deficits (Jiang & Huang, 2001). Summer-active perennial forage species capable of withstanding not only heat wave conditions, but soil moisture deficits are consequently needed. However, there is a paucity of information regarding the heat tolerance of perennial forages. To address this need, the tolerance of a range of species to heat wave conditions with and without irrigation was assessed. Tolerance was defined as a species' ability to support high growth rates during or shortly after the cessation of stress. Only temperate grazeable perennial species were considered in this study, due to their less frequent re-establishment requirements relative to annuals, and suitability to grazing systems.

Methods

Ten species were evaluated, but for the purposes of this paper only key ryegrass cv. Samson and chicory (*Cichorium intybus* L., cv. Grasslands Puna) results are presented. This study was undertaken in two independent chambers, within a greenhouse facility. Plants were established for 255 d, during which defoliations were undertaken at regular intervals. Treatments were imposed in a randomised split-plot design, with the combination of block and temperature regime the main-plot, stress durations assigned to subplots, and the combinations of species, moisture availability and recovery time randomly distributed within subplots. Temperature regimes (14/10 h day/night) consisted of an optimal and heat wave (day/night Ta of 23/15˚C or 38/26˚C) treatment; with temperature regimes maintained for 6, 12, or 18 d stress durations. Each chamber contained only one main-plot at any time; to minimise pseudoreplication main-plots were rotated between chambers at 3 d intervals, so that each main-plot by stress duration spent equal time in both chambers. Moisture levels were optimal watering (daily to through drainage) or no water. The combination of an optimal temperature regime and irrigation is here on referred to as the control treatment. At the conclusion of a stress period, plants were harvested or returned to an optimal temperature (day/night Ta, 23/16˚C) and watering regime for 18 d. At the end of each stress duration by recovery period treatment, herbage above 50 mm was harvested, dried for at least 48 h at 60˚C, and weighed. Maximal photochemical efficiency of photosystem II (PSII; F_v/F_m) was measured on dark adapted plants at the end of each stress period, using an OS-30p Chlorophyll Fluorometer (Opti-Sciences, Hudson, NH, USA).

Data was analysed as a split plot design. Quantile-quantile plots of residuals were examined, with transformations required for yield (square root) and F_v/F_m $[(F_v/F_m)/(1-F_v/F_m)]$ data. Yield data from the final establishment defoliation was included as a covariate in the yield analysis. Data were analysed using the PROC MIXED procedure of SAS 9.3, with comparisons of means using appropriately constructed contrasts. Associated P values were adjusted using PROC PLM (Edwards & Berry, 1987). All estimated mean and standard error values presented have been back-transformed. Differences discussed were significant at the $P < 0.05$ level.

Results

Both species recovered from water deprivation, regardless of stress duration (Table 1). Ryegrass was unable to recover from the combined stress of heat wave temperatures and water deprivation, when applied for 12 and 18 d. In contrast chicory recovered from both durations of the combined stress, yielding 57% and 23% of that attained by their control treatment contemporaries (Figure 1; Table 1). During the recovery period the yield of chicory exposed to the combined stress for 12 and 18 d increased by 180% and 46%, respectively.

Figure 1. Perennial ryegrass (*Lolium perenne* L.; Left) and chicory (*Cichorium intybus* L.; Right) after an 18 d recovery period from 18 d of heat wave stress and water deprivation.

Yields of each species at the end of each stress period were unaffected by duration, when exposed to water deprivation and either optimal or heat wave temperatures (Table 1). No yield differences were observed between these treatments, for each species, at each stress duration (Table 1). Ryegrass exposed to heat wave temperatures and water deprivation for 12 and 18 d had lower F_v/F_m levels than their control treatment contemporaries. Under irrigation neither the yield nor F_v/F_m of each species differed between temperature treatments, at the end of each stress period (Table 1).

Table 1. Ryegrass and chicory F_v/F_m and dry matter production when exposed to contrasting temperature regimes (*O* = Optimal, *H* = Heat wave) and moisture availability levels (*Irr* = optimal watering, *Dry* = no water) for different durations, with and without a recovery period (denoted, *R0* and *R18*). Values are back-transformed means ± 1 SE.

Species	Main-plot	Recovery	Stress Duration		
			Short (6 d)	Medium (12 d)	Long (18 d)
			F_v/F_m (arb. units)		
Perennial Ryegrass	*OIrr*	*R0*	0.833 ± 0.007^{Aa}	0.830 ± 0.008^{Aa}	0.828 ± 0.008^{Aa}
	ODry	*R0*	0.831 ± 0.008^{Aa}	0.806 ± 0.010^{Aa}	0.048 ± 0.240^{Bb}
	HIrr	*R0*	0.823 ± 0.008^{Aa}	0.818 ± 0.010^{Aa}	0.806 ± 0.010^{Aa}
	HDry	*R0*	0.805 ± 0.010^{Aa}	0.017 ± 0.256^{Bb}	0.025 ± 0.252^{Bb}
Chicory	*OIrr*	*R0*	0.841 ± 0.007^{Aa}	0.840 ± 0.007^{Aab}	0.838 ± 0.007^{Aab}
	ODry	*R0*	0.842 ± 0.007^{Aa}	0.849 ± 0.006^{Aab}	0.851 ± 0.006^{Aa}
	HIrr	*R0*	0.842 ± 0.007^{Aa}	0.855 ± 0.006^{Aa}	0.853 ± 0.006^{Aa}
	HDry	*R0*	0.842 ± 0.007^{Aa}	0.819 ± 0.009^{Ab}	0.801 ± 0.010^{Ab}
				Dry matter (g/pot)	
Perennial Ryegrass	*OIrr*	*R0*	5.87 ± 0.04^{Bab}	10.95 ± 0.04^{Aab}	12.38 ± 0.03^{Aab}
		R18	15.59 ± 0.03^{Baba}	20.73 ± 0.03^{ABaa}	24.85 ± 0.03^{Aaa}
	ODry	*R0*	5.17 ± 0.04^{Aab}	5.00 ± 0.04^{Abcb}	5.35 ± 0.04^{Abb}
		R18	13.58 ± 0.03^{Aaba}	$13.11 \pm \mathbf{0.03}^{ABba}$	9.31 ± 0.04^{Bba}
	HIrr	*R0*	5.10 ± 0.04^{Bab}	7.04 ± 0.04^{ABabb}	9.17 ± 0.04^{Aab}
		R18	17.47 ± 0.03^{Aaa}	17.57 ± 0.03^{Aaba}	22.36 ± 0.03^{Aaa}
	HDry	*R0*	4.03 ± 0.04^{Aab}	3.29 ± 0.05^{Aca}	3.16 ± 0.05^{Aba}
		R18	11.92 ± 0.03^{Aba}	4.05 ± 0.04^{Bca}	3.18 ± 0.05^{Bca}
Chicory	*OIrr*	*R0*	4.17 ± 0.04^{Bab}	6.47 ± 0.04^{ABab}	9.91 ± 0.04^{Aab}
		R18	11.54 ± 0.03^{Baba}	12.67 ± 0.03^{Baa}	18.12 ± 0.03^{Aaa}
	ODry	*R0*	3.31 ± 0.05^{Aab}	3.91 ± 0.05^{Aabb}	3.91 ± 0.05^{Abb}
		R18	8.95 ± 0.04^{Aba}	11.12 ± 0.04^{Aaba}	9.65 ± 0.04^{Aba}
	HIrr	*R0*	4.37 ± 0.06^{Bab}	6.42 ± 0.04^{ABab}	9.10 ± 0.04^{Aab}
		R18	15.62 ± 0.04^{Aaa}	14.56 ± 0.03^{Aaa}	16.13 ± 0.03^{Aaa}
	HDry	*R0*	3.18 ± 0.05^{Aab}	2.59 ± 0.05^{Abb}	2.85 ± 0.05^{Abb}
		R18	8.46 ± 0.04^{Aba}	7.24 ± 0.04^{Aba}	4.15 ± 0.04^{Bca}

Values followed by the same letters do not differ ($P < 0.05$); upper-case letters compare species across stress durations within main-plot by recovery period treatments; lower-case letters compare between main-plots (*OIrr* vs. *ODry* vs. *HIrr* vs. *HDry*) within each stress duration for each species by recovery period combination; lower-case underlined letters compare between recovery periods (*R0* vs. *R18*) within stress durations for each species by main-plot combination.

Discussion/Conclusion

Neither species grew after the first 6 d of heat wave temperature and moisture deficit stress. Chicory unlike ryegrass recovered, evidenced by yield increases of 180% and 46% over the recovery period from 12 and 18 d of the combined stress, respectively. After recovery from 12 and 18 d of the combined stress, chicory yielded 57% and 23% of their control treatment contemporaries. Explanation is provided by the high photochemical efficiency of PSII in the youngest fully-emerged chicory leaves during the stress period, indicating that the combined stress had minimal effect on the photosynthetic capacity (Jiang & Huang, 2001). Despite senescence being observed in older leaves, the maintenance of some leaves with undamaged photosynthetic apparatus would support the recovery growth seen in chicory, when returned to optimal conditions. In contrast ryegrass exposed to the combined stress for 12 and 18 d had very low F_v/F_m levels (0.017-0.025), attributed to widespread above-ground tissue senescence. It is suggested that whole-plant death occurred, given the inability of ryegrass to recover.

The combined stress also had a greater effect than either stress in isolation, as temperature had no effect on the yield and F_v/F_m of either species under irrigated conditions. Furthermore, both species recovered from moisture deficit in isolation, regardless of duration. Interestingly, heat wave temperatures had no additional

impact on the yield of either species during the stress period, when subject to water deprivation. This is because neither species grew after the first 6 d of water deprivation, regardless of temperature. It is concluded the survival capacity of chicory during extended periods of the combined stress underlies the superior tolerance of this species, enabling the resumption of production on return to optimal conditions, not possible with ryegrass. Chicory could potentially be used to mitigate the detrimental impacts of these stresses on dryland systems. This is particularly important, due to the regular occurrence of soil moisture deficits and increasing frequency of heat waves in SE Australia (Neal et al, 2009; Parker et al, 2014). Despite the low likelihood of comparable heat waves temperatures occurring for ≥ 12 d in SE Australia during the short-term (BOM, 2014), such conditions would be expected to more rapidly effect the survival of ryegrass already experiencing soil moisture deficits. A possible explanation is provided by the high moisture content of the potting media at the commencement of treatments, meaning that moisture deficits developed progressively. Declines in moisture content would have reduced the capacity of plants to mitigate heat stress via transpirational cooling.

The finding that the yield and F_v/F_m of irrigated plants was independent of temperature treatment, suggests that irrigation may be used as a management strategy to alleviate detrimental high temperature effects. However, this finding contrasts with previous studies reporting reductions in ryegrass growth at temperatures above 29.4˚C, and F_v/F_m level after 6 d of comparable heat stress (Mitchell, 1956; Jiang & Huang, 2001). A possible explanation for this discrepancy is the large pot volume used, which may have contained sufficient moisture to support evaporative cooling throughout the day.

In conclusion the key finding of this study was the ability of chicory to recover from combined heat stress and moisture deficit, when applied for 12 and 18 d. These conditions caused ryegrass to senesce. Future research will confirm these findings under field conditions, and elucidate the mechanisms underlying chicory's tolerance to combined heat stress and moisture deficit. Potential irrigation strategies for mitigating heat stress in existing ryegrass pastures will also be investigated.

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Increasing the seed production of summer-dormant, drought-tolerant cocksfoot

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Abstract

Recent research has demonstrated summer-dormant, hispanica cocksfoots (*Dactylis glomerata* spp *hispanica Roth*.) to be amongst the most drought-tolerant temperate perennial grasses yet commercialised. However, whether cultivars of this subspecies become available to farmers is dependent upon seed growers being able to produce seed profitably and so far this has been problematic. Australian seed growers can profitably grow seed of *Dactylis glomerata* spp *glomerata* cultivars at plant densities of 180-200 plants/m^2 or less so trials were established to identify whether such low, commonly-used densities are a constraining factor that might require modification to obtain commercially acceptable seed yields in hispanica cultivars. A field trial comparing *Dactylis glomerata* spp *glomerata* cv Currie with *Dactylis glomerata* spp *hispanica* cv Kasbah, each sown at 3 plant densities (200, 400 and 500 plants/m^{-2}), was established. A dry finish to the growing season caused seed yield of the later flowering cv Currie to be significantly reduced (347 kg/ha) in comparison to the earlier flowering Kasbah (450 kg/ha) and although at this stage any density-related yield differences were non-significant indications were that yield of Kasbah might increase with plant density. An earlier pot trial had also indicated that seed yield of Kasbah was most sensitive and reduced if the crop experienced water stress within the Zadoks growth stage range of 56.6 (75% inflorescence emerged) to 63.8 (50% anthesis), than at growth stages either before or after this range. These results have implications for those growers with available irrigation. Research continues to study the effects of plant density on seed yield focussing on older mature swards.

Keywords

Orchard grass, Spanish cocksfoot, plant density, moisture deficit, germination, hispanica cocksfoot

Introduction

The first cultivars of *Dactylis glomerata* spp *hispanica* to be developed in Australia, cvv. Kasbah and Berber, were bred by J. Carpenter at the Waite Institute in the late 1960's, and were then released as public cultivars (Oram 1990). Both cultivars, derived from populations collected in the semi-arid regions of southern Morocco, express high levels of summer dormancy and consequently are very drought tolerant (Norton *et al*. 2006a). These cultivars were effectively lost to Australian agriculture during the next two decades of the 1970's and 1980's when low commodity prices of wool, beef and sheep meat caused farmers in the drier mixed farming zones to reduce investment in pasture improvement (Rex Oram pers. com.). The droughts of the 1980's however, led to a rekindling of interest in drought tolerance traits among researchers and the rediscovery of the potential of summer dormancy to improve persistence. The superior drought tolerance conferred by the summer dormancy trait has been reconfirmed in the southern Australian droughts of the past two decades during which cv Kasbah has consistently persisted better than many other cultivars or species especially when the dry periods became severe and extended (Norton *et al*. 2001; Hackney *et al*. 2006; Hayes *et al*. 2010a). This work with perennial grasses complemented concurrent discoveries in farming systems research showing that pastures containing perennial species tended to confer greater sustainability benefits than those reliant upon annual species because of their greater soil water use, and ability to reduce the rate of nitrate leaching.

However, the extension of this technology was frustrated largely by the unavailability of seed of these grasses. This is primarily because seed growers were unable to obtain commercially viable yields of these hispanica cultivars. The reason for this is unclear as it may either be due to inappropriate agronomic recommendations such as inadequate plant density or, as has been suggested by seed company agronomists, that hispanica, summer-dormant cultivars such as Kasbah are inherently of low seed yielding capability. Australian grass seed producers have extensive experience of successfully growing seed of *Dactylis glomerata* spp *glomerata* cultivars such as Currie and Porto. However, using the same agronomic recommendations they are unable to consistently produce seed of *Dactylis glomerata* spp. *hispanica*

cultivars profitably. Surveying of seed industry agronomists prior to the commencement of the research reported here indicated that the plant density of Kasbah cocksfoot seed crops rarely exceeded 180-200 plants m^{-2} and was often lower. It is important to note that these are the densities recommended for cultivars of *glomerata* cocksfoots such as Porto or Currie. Furthermore, there appears to be no research published on this topic although some work was undertaken suggesting that plant densities much higher (400 plants /m^2) than those commonly found in farmer fields were necessary to maximise seed yields in cv Berber, a plant of similar morphology to Kasbah (J. Carpenter unpublished research). Carpenter (1968) also observed that even though Berber and Kasbah originated in semi-arid environments their seed yield could be severely restricted if plants experienced moisture deficit during reproductive growth. Given that there is renewed interest in producing seed of *hispanica* cocksfoot cultivars and that some of this production is likely to occur in regions where irrigation is available, it is timely to consider the role of plant density in seed yield production and to identify that period of reproductive growth when seed development of the hispanic cocksfoot plant is most constrained by moisture deficit. Consequently, two trials were undertaken, one in the field comparing two cocksfoots of different subspecies and morphologies under three different plant densities, and the other in the glasshouse examining the effect of moisture deficit applied to cv Kasbah at different stages during reproductive growth.

Materials and Methods

In the field trial two cultivars were selected for study, *Dactylis glomerata* spp *glomerata* cv Currie and *Dactylis glomerata* spp *hispanica* cv Kasbah (Oram 1990). Currie was considered to be an appropriate cultivar against which to compare Kasbah as it has been available since the late 1950's and there is consequently considerable experience and confidence among seed growers in dealing with this cultivar. Each cultivar was sown at a rate sufficient to obtain plant densities of 200, 400 and 500 plants/m^2 taking into account variation in seed weight, germination percentage and the likely establishment achieved. Each plot was 4.6 m^2 in area, with rows spaced 20 cm apart and the experiment was arranged as a randomised complete block design with four replications. The trial was located at the Ginninderra Research Station of CSIRO in Canberra (35.18 S, 149.06 E, 610 m altitude) at a freely draining location in the paddock. The soil at the test site was a yellow sodosol (Isbell 1996). Sowing occurred in early spring on the 3rd September 2012. Fertiliser was applied at that time at the rate 22.5 kg N/ha and 19 kg P/ha and in early September 2013, N was applied at 50 kg/ha. Seed harvest did not occur until early January of the following season, 2013/2014, at which time 2 m of row was randomly selected from each plot and harvested for seed yield. The seed was threshed, cleaned and tested for germination.

A second trial to examine the effect of moisture deficit occurring over the period of reproductive growth in cv Kasbah was also undertaken. Three Kasbah plants were grown in 20 cm wide pots each containing approximately 5.5 kg of a freely-draining potting mix. The period during which moisture deficit was imposed began on 14 September (day 258 of the year) and continued until 6 November (day 311 of the year). The pots were divided into seven groups of eight pots with each group experiencing a period of water deficit once (a period of 7 to 8 days) during the reproductive growth period. Water deficit was imposed by withholding irrigation from the group of pots during this period. Relative water content (Barrs and Weatherley 1962) of the youngest fully expanded leaf was used to measure the degree of plant water deficit experienced on the last day that moisture was withheld on four different droughted pot groups throughout the trial period. Growth stage was also measured on all plants during this trial using the system of Zadoks et al(1974). Data analyses employed ANOVA in Genstat for Windows 16.

Results and Discussion

Although Canberra received 622 mm in 2013 which is close to the mean annual rainfall, only 20 mm of this fell in October in the months leading up to seed harvest (Table 1). This is substantially less than the median rainfall of 55 mm which can be expected in October.

Seed yields of the different plant densities and cultivars are presented in Table 2. In this trial there were no significant differences due to plant density and any interaction between cultivar and plant density was also not significant. However, the mean seed yield of cv Kasbah across the 3 plant densities was 450 kg/ha, significantly greater than the yield of cv Currie, 347 kg/ha. The lower yield limit for a seed crop of cocksfoot

to be considered commercially is approximately 400 kg/ha (N. Phillips, G. Stewart pers. com.). Accordingly the yield of cv Kasbah was high enough to be commercially viable whereas cv Currie did not achieve this seed yield level.

Given that Kasbah flowered in early September whereas Currie flowered almost one month later in late September / early October (Oram 1990) it seems likely that the dry October conditions impacted more severely on seed yield development of the later flowering Currie than on the earlier flowering Kasbah.

Table 1. Monthly rainfall (mm) and mean monthly maximum and minimum temperatures at Gininnderra Research Station during the period from trial sowing (September 2012) to seed harvest (January 2014).

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Rain	53	78	33	56	85	79	28	10	12	108	56	29	69	20	105	21	8
Max Temp.	16	20	24	27	32	26	24	21	16	12	12	13	18	20	23	28	31
Min Temp.	3	5	10	13	15	14	12	7	4	3	3	3	6	5	8	12	13

Nevertheless, the results suggest that a positive correlation between plant density and seed yield might exist in cultivar Kasbah under growth conditions where moisture deficit during the reproductive stage is less severe. This is possible because a non-significant yield increase of 130 kg/ha, occurred in Kasbah with 500 plants/m^2 compared to 200 plants/m^2. Certainly this possibility deserves ongoing investigation. In addition, as this was a first year crop, on-going studies are necessary to measure seed yield with older, mature swards of this perennial grass. Indeed to assess commercial viability it will be necessary to maintain the crop swards for a number of years before a full evaluation of the effects of the different plant densities can be obtained.

Table 2: Seed yield (kg/ha) of the cocksfoot cultivars, Currie and Kasbah, sown at three plant densities.

Plant density (plants/m^2)	Currie	Kasbah
200	315	387
400	364	446
500	362	517

In the trial to study the effect of moisture deficit imposed at different plant growth stages on seed yield and germinability the measurement of relative water content (RWC) was undertaken to verify that the withholding of irrigation from the droughted pots did succeed in imposing a substantial level of moisture deficit on the affected plants. Thus RWC was measured on plants from 6 pots of both droughted and fully irrigated plants on the 17th and 25th October and the 1st and 9th November.

Table 3: The effect of moisture deficit imposed at different plant growth stages on seed yield and seedlot germination of Kasbah cocksfoot.

Zadoks growth stage/date/day of year	Seed yield (g)	Seedlot germination (%)
55.4/ 18 Sept/ 261	4.846	78.3
56.6/ 24 Sept/ 267	1.123	2.6
57.9/ 3 Oct/ 276	2.613	24.7
61.3/ 12 Oct/ 284	2.67	24.2
63.8/ 19 Oct/ 292	2.501	11.6
66.2/ 26 Oct/ 299	3.211	49.2
66.8/ 2 Nov/ 305	4.58	70.6
LSD (P>0.05)	**1.572**	**26.1**

The values of RWC measured on these dates were 30, 35, 32 and 46% for the droughted plants and 94, 91, 98 and 95% for the well-watered plants, indicating that the withholding of irrigation did subject the plants to substantial moisture deficit.

The stage of reproductive growth during which moisture deficit was imposed had a pronounced effect on both seed yield and seedlot germinability (Table 2). Thus moisture deficit imposed at the earliest growth stage tested (Zadoks 55.4, 50% infloresence emergence) had much less effect on both yield and germinability than when the deficit was imposed just 6 days later at Zadoks 56.6. Seed yield and seedlot germinability seemed to be most reduced by moisture deficit when imposed during the period when the growth stages ranged from Zadoks 56.6 (75% inflorescence emerged) to 63.8 (50% anthesis).

Conclusions

These two trials indicate that moisture deficit during reproductive growth can have a major negative impact on seed yield and germinability of cocksfoot. Irrigation, if available and applied during this period should be able to overcome this constraint. Studies of the effect of plant density on seed yield were inconclusive but provide support for the need to continue research on this topic as it is possible that when moisture deficit is not so severe, seed yield may be positively correlated with plant density. On-going measurement of the effects of plant density on seed yields in older, mature swards is also required as under commercial conditions cocksfoot grass seed crops must be maintained for several years and it is possible that plant density may change over time.

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Stoloniferous red clover cv. Rubitas is a valuable companion to PRG and phalaris

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Abstract
In established pasture swards, legumes contribute and transfer nutrients to non-legume species, but are thought to contribute and transfer little during the establishment phase. The nutrient contribution of stoloniferous red clover *Trifolium pratense* cv. Rubitas during the pasture establishment phase may have been underestimated. To test this hypothesis a pot study was sown in April 2014. Perennial ryegrass *Lolium perenne* (PRG) cv. Reward was sown alone at 25kg/ha or in combination at two sowing rates, 12 and 20kg/ha with Rubitas at 5kg/ha. Phalaris (*Phalaris aquatica*) cv. Advanced AT was sown alone at 5kg/ha or with 3kg/ha Rubitas. Rubitas was also sown alone at 6kg/ha. After establishing for 75 days, plants were exposed to defoliation intervals of 10, 20 and 40 days defoliated 8, 4 and 2 times, respectively. These defoliation interval treatments were combined with three residual heights of 25, 50 and 100 mm. Material harvested was hand separated into species, weighed and dried. Results for all treatments and means showed a significant ($P<0.0001$) effect of species, defoliation interval, species by defoliation interval and residual height by defoliation interval. For treatments that included Rubitas, there was a significant ($P<0.0001$) increase in DM yield of the companion grass when compared to the PRG or phalaris sown alone. The inclusion of Rubitas increased the combined DM yield of PRG and phalaris by 72% and 179% respectively compared to PRG or phalaris sown alone. Rubitas nutrient contribution and transfer may affect regrowth recovery after defoliation. Further work will seek to quantify Rubitas establishment mechanisms and enhance management for economic and environmental gains.

Key words
Companion sowings, pasture establishment, defoliation intervals

Introduction

Legumes including members of the *Trifolium* genus have a symbiotic relationship with nitrogen (N) fixing bacteria when they are fully established actively nodulating plants (Boller and Nösberger, 1987; Høgh-Jensen and Schjørring, 1997). The method that the roots of the legumes use to establish contact with symbiotic bacteria is not clearly defined. Previous research in forest ecosystems suggest an exudate is generated from leguminous trees to grasses, as an attractant to N fixing bacteria in the soil (Sierra et al., 2007). If this is occurring in pasture mixes of clover and grass (Lesuffleur et al., 2013), grasses may also be seeking out this medium to aid in rapid root establishment. Perennial ryegrass (PRG) and white clover *Trifolium repens* pastures are commonly used to support intensive grazing animal production (Cunningham et al., 1994). Clovers are often observed to be the less dominant component of a grass/clover composite sward under intensive grazing management systems, particularly for those fertilized with increasing rates of synthetic N fertiliser.

Mature decaying clover roots, shoots and leaves release N back into the soil to be taken up by plant roots (Evans, 1977) and recycled again (Dahlin and Stenberg, 2010; Unkovich, 2012). During establishment the N contribution is less defined. The productivity of clover is influenced by establishment strategies that enhance legume content and pereniality as longer established swards hold larger nutrient reserves in the soil (Peoples et al., 2013). It is claimed that clovers do not contribute to the N pool until decaying plant parts became part of the soil nutrient pool (Laidlaw et al., 1996; Ledgard and Steele, 1992). The presence of a clover companion during establishment is not expected to improve the DM yield of the grass.

Following sowing, grazing management during establishment is critical to achieving a productive and persistent pasture. Defoliation interval and defoliation residual heights have been intensively studied in

established PRG/white clover pastures (Chapman et al., 1996; Rawnsley et al., 2014) but little work has been done with stoloniferous red clover and grasses during the establishment phase.This experiment aimed to investigate the effects of varying defoliation interval and residual height treatments on dry weight (DM) yields during the establishment of differing mixed clover and grass swards.

Methods

Six pasture treatments were sown in 200 mm pots as monocultures of stoloniferous red clover cv. Rubitas 6 kg/ha, Reward PRG 25 kg/ha, Advanced AT phalaris 5 kg/ha and combinations of Rubitas 5 kg/ha & Reward 20 kg/ha, Rubitas 5 kg/ha & Reward 12 kg/ha, Rubitas 5 kg/ha & Advanced AT 3 kg/ha. Pots were initially located outside and species treatments sown in April 2014. In May, 35 days after sowing (DAS) four replicates of each treatment were placed in a glasshouse maintained at 20oC± 5□C, arranged as a completely randomised design. Rubitas stoloniferous red clover was scarified and inoculated with Rhizobium Group B. At 30 DAS fertiliser Starter blend 20%N, 21%P + 4%Mg was applied at an equivalent rate of 1000kg/ha. Trace elements Basix Reset™ was applied at 31 DAS at an equivalent rate of 15L/ha containing 100g B, 136g Fe, 104g Mn, 1800g Zn, 192g Cu and 94g Mo per 15L of concentrate diluted with 120 L water.

Potassium as sulphate at 50kg/ha equivalent rate was applied at 66 DAS. Plants were thinned to represent plant density for each sowing rate. At 65 DAS all treatments received a co-variant cut to 50 mm. The first defoliation treatments commenced 75 DAS. Treatments were defoliated for 80 days at 10, 20, and 40 days to residual heights of 25 mm, 50 mm, and 100 mm and re- randomised after each defoliation interval. All material was cut, collected, weighed, hand separated into species composition and dried at 60 oC for 48 hours. Cumulative dry matter (DM) yields were analysed using proc mixed in SAS 9.3 assuming a completely randomised design. After examining quantile plots of residuals a log transformation was selected. Effects were considered significant at P<0.05.

Results

Fixed effects for all treatments showed significant effects ($F_{5, 157}$=63.15, P<.0001) of species and species by defoliation interval ($F_{10, 157}$=5.95, P<.0001).The effect of residual height or species by residual height was not significant (P>0.05). Comparing species effects (Table 1) the DM results were consistently higher (P<0.0001) when Rubitas was sown as a companion with PRG. Similarly, Phalaris sown with Rubitas produced more DM than phalaris sown alone. There was no significant (P>0.05) difference in PRG yield at the higher and lower sowing rates of 20 or 12 kg/ha when sown in combination with Rubitas. In comparing the grass yield component only, when sown with Rubitas the PGR yield increased by 27% and 32%, at 20 and at 12 kg sowing rate, respectively. Similarly, the phalaris component yield of the phalaris/Rubitas treatment was 72% higher than phalaris sown alone.

Table 1.The cumulative mean dry matter yield (kg DM/ha) of each species treatment. Values presented are the back transformed means. Values in parenthesis are the transformed means ± the standard errors % clover and grass shown for monoculture and combination treatments

species	Yield (kg/DM /ha)	% clover	% grass
Reward PRG	853.2 (6.7±0.2)	0	100
Reward20/Rubitas	1414.3 (7.1±0.2)	20	80
Reward12/Rubitas	1511.6 (7.2±0.2)	24	76
Advanced AT phalaris	361.9 (5.8±0.2)	0	100
Advanced AT/Rubitas	1008.7 (6.6±0.2)	43	57
Rubitas	869.5 (6.4±0.2)	100	0

There was a significant (P<0.0001) species by defoliation interval effect on DM yield (Table 2). A defoliation interval of 40 days resulted in a 71% and 60% decline in cumulative DM yield in comparison to defoliation intervals of 20 and 10 days, respectively. A defoliation interval of 20 days resulted in a significantly higher (37% increase) cumulative DM yield in comparison to a defoliation interval of 10 days.

Table 2.The cumulative dry matter yield (kg/DM/ha) for each species treatment by each defoliation interval treatment. Values presented are the back transformed means. Values in parenthesis are the transformed means ± the standard errors

species	defoliation interval		
	10 days	20 days	40 days
Reward PRG	864.1	1218.1	477.3
Reward20/Rubitas	1466.1	2011.0	765.6
Reward12/Rubitas	1713.2	2180.5	641.0
Advanced AT phalaris	313.8	527.6	244.4
Advanced AT/Rubitas	1239.3	1494.4	292.4
Rubitas	902.0	1498.3	208.2
average	1083.11	1488.3	438.2
SE	(6.8±0.2)	(7.2±0.2)	(5.9±0.2)

Discussion

The legume of choice in high production irrigated systems is white clover. White clover has a tap root not unlike red clover initially. The tap root is replaced with adventitious roots at around two years after sowing white clover (Black et al., 2009). Storage of nutrients is somewhat restricted after this occurs in white clover. Rubitas may improve yield as a legume companion with grasses.This plant unlike other red clovers has a distinct advantage as it is stoloniferous. This attribute makes it more suited to repeated defoliation (Seresinhe et al., 1994; Van Minnebruggen et al., 2014) giving it some similarity in management to white clover. The inclusion of Rubitas as an alternative legume to white clover may suit irrigated pastures sown in autumn or spring.

In this experiment both PRG and Phalaris produced higher DM yield when sown with Rubitas as a legume companion. Defoliation interval was shown to be important but residual height had no effect on DM yield. Rate of sowing in PRG had no effect on DM yield in this study. Reward PRG sown as a monoculture was similar in DM to Rubitas sown alone suggesting a combination of the two species would produce a similar DM yield. However, in this study the yield was shown to be greater in the companion sowing than in the monoculture combined yields. In the Advanced AT / Rubitas mixed sward the individual DM of phalaris and Rubitas was similar to when they were sown together. Advanced AT is slow to establish and the lower DM yield was possibly due to the absence of leaf during this stage.

Defoliation interval results across all treatments support the current thinking that more frequent defoliation can decrease DM production. With a high frequency of defoliation as shown in the 10 day defoliation interval, some depression in DM yield would be expected. When the defoliation frequency was extended to 40 days a larger depression in yield occurred. The 20 day interval was found to be optimal for defoliation and regrowth even with three residual heights imposed under the growing conditions that where experienced. The species selected and the defoliation interval treatments imposed, favoured a response to 20 days based on PRG optimum interval for regrowth. The increase in DM produced at establishment with PRG cannot be explained by inclusion of Rubitas. The slower establishing phalaris when sown with Rubitas showed greater increases in DM yield which was attributed to the presence of Rubitas.

Conclusion

Rubitas red clover has the potential to contribute at establishment, as well as the longer term life of the pasture in combination with PRG or phalaris. The mechanism by which DM yield is affected and enhanced by the inclusion of Rubitas needs explanation. Measurement of components in the grass/clover composite sward and growth indices would add greatly to the knowledge of establishment interaction. Future field experiments should include white clover combinations as well as Rubitas when testing establishment effects on DM.

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Comparing within paddock yield variability of perennial ryegrass monocultures and perennial ryegrass, white clover and plantain mixtures using yield mapping

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Abstract
Diverse mixtures of pasture species have greater potential for exploiting niches within a paddock compared to monocultures resulting in less variability in pasture growth within the paddock. It is unknown if the variability occurs at a scale that is relevant in intensively managed dairy systems. This study assessed the variability in pasture biomass within 6 split paddocks sown to either perennial ryegrass monocultures (PRG) or perennial ryegrass, white clover and plantain mixtures (RCPM) on a dairy farm in north-west Tasmania. The biomass present in each area was mapped immediately prior to grazing in the spring of 2014 and autumn 2015 using a C-Dax pasture meter with a GPS console. Data was interpreted through the Manifold GIS software before being analysed in the R statistical package. There were no significant difference in pasture biomass between the PRG and RCPM treatments, with mean pasture biomass of 2997 and 3162 kg DM/ha respectively. The variation in pasture biomass within each area (as assessed by the co-efficient of variation) was greater in the PRG areas (16.6%) than in the RCPM areas (13.4%). The overall difference between the within plot standard deviation and coefficient of variation for the treatments was small at 65 kg DM/ha and 3.2% respectively. Diverse pastures have increased opportunities to exploit niches existing within dairy paddocks relating to soil diversity. This and other studies suggest that exploitation of niches only has a small impact upon within paddock yield variability.

Key words
Pasture mixtures, yield mapping, niche exploitation

Introduction

Diverse pasture mixtures containing grasses, legumes and forbs have been shown to out yield grass-legume binary pasture mixtures and grass monocultures by between 9 and 15% on dairy farms, in the temperate regions of New Zealand and Australia (Nobilly *et al*. 2013, Tharmaraj *et al*. 2008, 2014). If the yield advantage of diverse pasture mixtures are to be fully and consistently exploited we must understand the mechanisms promoting increased yield. It has been proposed that the exploitation of niches within the pasture is the primary driver of the increased yields (Pembleton *et al*. 2015). This means diverse pasture mixtures should have less within paddock variation for yield than less species diverse pastures.

Yield mapping allows for the effective and simple assessment of variability in yield within a field (Stafford et al. 1996). It has been used extensively to evaluate the within field variability in many crop production systems from cereal crops (Stafford *et al*. 1996) to orchards (Schueller *et al*. 1999). However, until recently these techniques have not been applied to intensively managed dairy pastures. The development of non-destructive, GPS enabled, rapid pasture biomass assessment tools (e.g. the C-Dax pasture meter) has made yield mapping of dairy pastures feasible (Dalley *et al*. 2014).

This study aimed to use yield mapping to evaluate variability in yield within diverse pastures comprised of perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and plantain (*Plantago lanceolata* L.) when compared to perennial ryegrass monocultures on a dairy farm in North West Tasmania. It was hypothesised that the diverse pasture mixture would have lower within paddock variability than the monoculture pasture.

Methods

This study was undertaken within the six fields comprising part of the area grazed by the milking herd at the Tasmanian dairy research facility (TDRF) at Elliott (41.08◦S, 145.77◦E) in northwest Tasmania. This location has a winter dominant rainfall pattern and an annual rainfall of 1200mm. Long term average maximum and minimum temperatures for January are 19.4 and 10.3°C respectively while for July they are 10.4 and 4.3◦C respectively.

During April 2012, large plots (ranging between 0.40 and 0.72 ha in size) were sown in to fully prepared seedbeds with either 25 kg/ha of perennial ryegrass cv. Base (from here on referred to as PRG) or a mixture of 20kg/ha of perennial ryegrass cv. Base, 2kg/ha of white clover cv. Kopu 2 and 1kg/ha of plantain cv. Tonic (from here on referred to as RCPM). The plots were first grazed during late August to early September 2012. Following this initial grazing event, the plots were managed as part of the rotational grazing program utilised at TDRF (grazed between the 2nd and 3rd ryegrass leaf stage to a residual biomass of 1400kg DM/ha). Plots received an annual application of phosphorus, potassium and sulphur fertilizer (to replace nutrient removal) and 3 applications of nitrogen fertiliser per annum (40kg N/ha/application).

A GPS map of each treatment plot was obtained using a Trimble® CFX 750 ™ GPS control unit mounted to a vehicle. RangePoint™ RTX™ correction was used to improve the accuracy of the GPS locations. Waypoints were obtained around the perimeter of the treatments in each of the paddocks using a two metre offset from the GPS antenna. These waypoints were downloaded from the Trimble® CFX 750 ™ console into the Manifold GIS software package (Manifold Software Limited, Wanchai, Hong Kong) to create the maps for each treatment plot and georeferenced using the Universal Transverse Mercator (UTM) coordinate system.

During September 2014 and during March 2015, in the week prior to the planned grazing event, the pasture yield of each treatment plot was mapped using a C-Dax pasture meter integrated with a GPS console (C-Dax Ltd, Palmerston North, New Zealand). Each plot was mapped using 2 m intervals. Between 240 and 725 measurements were taken per plot. Data from the C-Dax pasture reader was downloaded into FarmKeeper software to produce an individual shape file (SHP) containing pasture yield data associated with corresponding GPS co-ordinates (point data) for each paddock. The mapping data was interpreted using Manifold GIS software before being analysed by the R statistical software package (R Core Team 2014). The mean biomass for each plot, along with the within plot standard deviation and coefficient of variation, was then subjected to an ANOVA as a randomised complete block design, using paddock as the blocks. To visually assess the variance in biomass between treatments the data was mapped using the 'fields' and 'RgoogleMaps' packages for R (Nychka et al. 2014, Loecher and Ropkins 2015).

Results

The total biomass of the PRG and RCPM treatment plots was similar in both the spring and autumn periods (Table 1). The biomass of the pastures ranged between 1659 and 3392 kg DM/ha and averaged 3080 kg DM/ha during spring (September –December) and 2305 kg DM/ha during autumn (March-May). The within plot variability, as assessed by the standard deviation and coefficient of variation in biomass, was greater in the PRG (monoculture) compared to the RCPM (diverse species) during spring. The overall difference between the within plot standard deviation and coefficient of variation for the treatments was small at 65 kg DM/ha and 3.2% respectively. In the autumn period there were no differences between the within plot standard deviation or coefficient of variation. A visual inspection of the yield maps (Figure 1) confirmed less variation in pasture biomass for the RCPM during the spring assessment and increased variation for the autumn assessment.

Table 1. The biomass as measured through yield mapping with a C-Dax pasture meter along with the standard deviation and coefficient of variation in biomass for each paddock in the study immediately prior to grazing in spring 2014 and Autumn 2015.

Paddock ID	Average biomass (kgDM/ha)		Standard deviation (kgDM/ha)		Coefficient of variation (%)	
	PRG	RCPM	PRG	RCPM	PRG	RCPM
			Spring 2014			
11	3043	3175	474	441	15.6	13.9
18	2879	3139	570	460	19.8	14.7
54	2500	3081	587	478	23.5	15.5
56	2788	2842	482	483	17.3	17.0
13	3380	3343	391	327	11.6	9.8
16	3392	3390	398	324	11.7	9.6
Mean	2997	3162	484	419	16.6	13.4
P value	NS	P<0.05	P<0.05			
			Autumn 2015			
11	2246	2176	280	615	12.4	28.3
18	2001	2086	459	438	22.9	21.0
54	1698	1659	241	264	14.2	15.9
56	1734	1687	225	186	13.0	11.0
13	3092	3139	494	529	16.0	16.9
16	3123	3009	586	476	18.8	15.8
Mean	2316	2293	381	418	16.2	18.1
P value	NS	NS	NS			

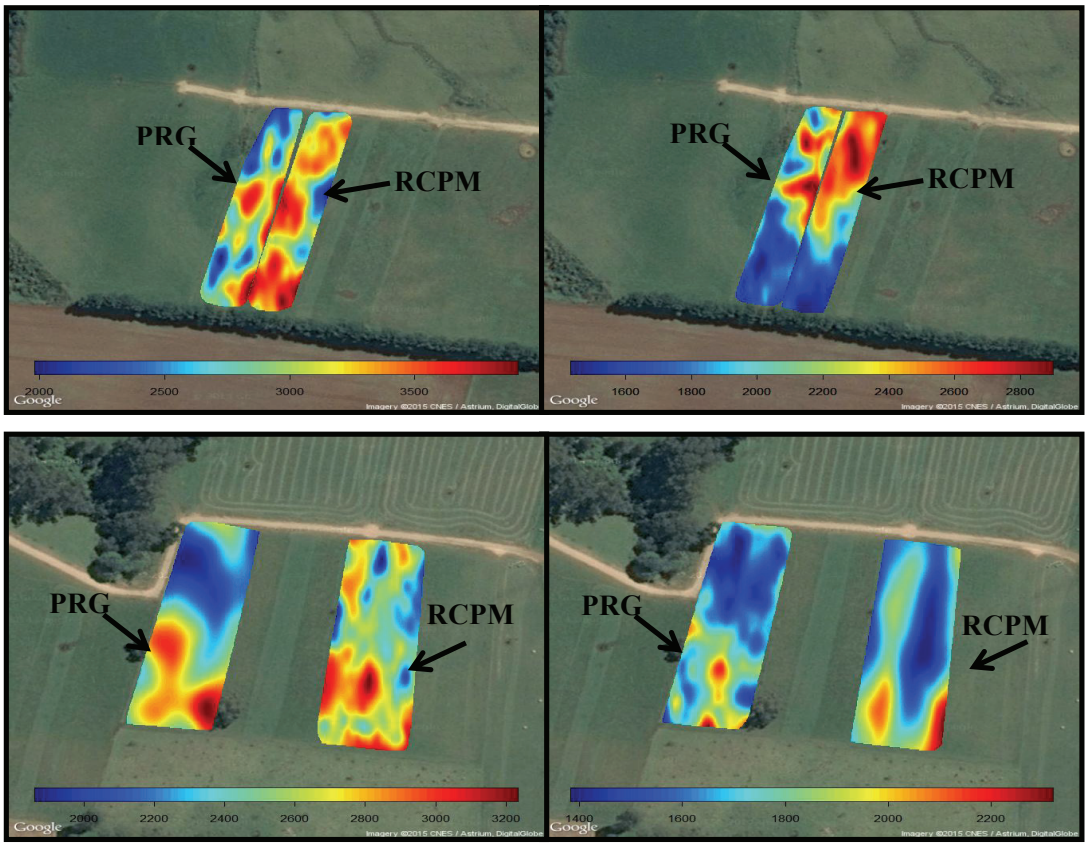

Figure 1. Yield maps of the perennial ryegrass monoculture (PRG) and perennial ryegrass, white clover and plantain mixture (RCPM) in paddock 18 (upper panels) and paddock 54 (lower panels) at the Tasmanian Dairy Research Facility prior to grazing in Spring 2014 (left panels) and Autumn 2015 (right panels).

Discussion

This study has highlighted that while diverse pasture mixtures can have less variability in pasture biomass compared to monoculture pastures; this variability is temporal in nature. This evidence confirms the hypothesis proposed by Pembleton *et al*. (2015) that the scale and levels of inputs applied to temperate dairy pastures means the niche exploitation achieved within these pastures occurring from increased species diversity is likely to occur temporally than spatially.

The decrease in variability in pasture biomass that occurred during spring was associated with fewer low yielding areas being present. While it was not clear from this study, a longer term analysis of the pastures has shown mixtures of perennial ryegrass, white clover and plantain have superior levels of forage production during spring compared to perennial ryegrass monocultures (K. G. Pembleton unpublished data). Low soil temperatures and/or water logging are some of the possible constraints to pasture production during spring at this location. Plantain has increased tolerance to water logging compared to perennial ryegrass (Banach *et al*. 2009). The cultivar of plantain used in this study, Tonic, is also noted for its high growth rates during the cooler months (Stewart 1996). These traits would have enabled plantain to exploit spatial differences in temperature and drainage during spring helping reduce the within paddock biomass variability.

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A preliminary evaluation of alternative annual legume species under grazing on the Southern Tablelands of NSW

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Abstract
A field experiment was established at Goulburn, NSW, to identify the likely potential of a range of alternative annual legume cultivars for use in grazing systems on the Southern Tablelands. One cultivar each of arrowleaf clover (*Trifolium vesiculosum*), purple clover (*T. purpureum*), balansa clover (*T. michelianum*), crimson clover (*T. incarnatum*), biserrula (*Biserrula pelecinus*), French serradella (*Ornithopus sativus)* and yellow serradella *(O. compressus)* was compared to subterranean clover *(T. subterraneum) cv. Leura* from 2013-15. All treatments were sown as monocultures at 20kg/ha and left ungrazed during the establishment year. In year two sheep grazed the experiment three times from February-August before stock were again excluded to enable legumes to set seed. Leura subterranean clover (7.0 t/ha) and Dixie crimson clover (6.3 t/ha) were the most productive annual legumes during spring of year 2 and the treatments with the lowest proportion of volunteer weed species (4% and 13%, respectively). By contrast, Mauro biserrula (0.5 t/ha) and Margurita French serradella (1.3 t/ha) were the least productive, with 88% and 75% of total available biomass in these swards composed of volunteer weed species, respectively. Seedling regeneration in year three was negligible in the purple clover, biserrula, French and yellow serradella swards. The poor performance of most alternative annual legume species under relatively lenient management is discussed in the context of introducing alternative annual legume species to permanent grazing systems in cooler more temperate environments. This study highlights the need to develop cultivars of these annual legume species specifically for this new target environment.

Key words
Hard seed; Mediterranean; regeneration; production; competition; weeds

Introduction

A high level of breeding, development and evaluation research has culminated in the commercial release of an unprecedented number of annual pasture legume species and cultivars on the Australian market over the past two decades (Nichols *et al*. 2007; Nichols *et al*. 2012). These alternative legumes were developed and tested in cropping systems and environments to provide forage for livestock and to fix atmospheric nitrogen (N) for subsequent crops. The broad range of cultivars with diverse traits now available provides an opportunity for growers to improve legume production by selecting cultivars suited to their environment and production enterprise. Initial evaluations of most presently commercialised species targeted environments in NSW on the Slopes and Plains (e. g. Dear *et al*. 2003; Boschma *et al*. 2011) with relatively little evidence to date of the performance of these species in higher rainfall Tablelands environments. The Tablelands are often dominated by grazing enterprises and experience cold wet winters, while the soils are frequently shallow and acidic. This study tested the potential adaptation of several alternative annual legumes species developed for cropping systems to an environment in the Southern Tablelands of NSW.

Method

A field experiment was sown near Goulburn using a cone seeder on 21 March 2013. Treatments were randomised in three replicates and included arrowleaf clover cv. Zulu II, purple clover cv. Electra, balansa clover cv. Bolta, crimson clover cv. Dixie, subterranean clover cv. Leura, biserrula cv. Mauro, French serradella cv. Margurita and yellow serradella cv. Santorini, all sown as monocultures in 2.5 ×10 m plots at a seeding rate of 20 kg/ha. The site was fallowed with herbicides for 18 months prior to sowing, and Spinnaker was applied at 70 g/ha as a post sowing pre-emergent selective herbicide. Prior to sowing, the site was limed at 5.0 t/ha and basal nutrients were applied to ensure no nutrients other than N were limiting. The treatments reported here were part of a larger experiment to evaluate the response of pasture species to P nutrition. We

report results from only the legume treatments at the highest P level which received triple superphosphate (20% P and 1.5% S) at sowing applied at a rate calculated to deliver 80 kg P/ha to ensure P was not limiting. All legume seed was inoculated with appropriate rhizobia groups (Table 1) and lime pelleted prior to sowing. An area around the trial site of approximately 2 ha was sown to various grasses and legumes which was later grazed in common with the experimental plots, to ensure a more realistic grazing pressure and to provide space away from the plots for stock water and camp sites.

Table 1. Approximate percentage of hard seed, required inoculum group and recommended rainfall required for annual legume cultivars included in the field experiment (adapted from Lattimore and McCormick 2012)**.**

Species	Cultivar	Hard seed levels (%)	Inoculum Group	annual rainfall (mm)
Arrowleaf clover	Zulu II	80	C	>400
Balansa clover	Bolta	90	C	>550
Biserrula	Mauro	95	WSM 1497	>400
Crimson clover	Dixie	<10	C	>450
French serradella	Margurita	85	S	>400
Purple clover	Electra	80	C	>550
Subterranean clover	Leura	<10	C	>700
Yellow serradella	Santorini	90	S	>400

Estimates of seedling establishment were made on 5 July by counting the numbers of seedlings in two 0.15 m^2 quadrats placed randomly in each plot. An assessment of first year biomass was made on 15 October 2013 by cutting herbage in one 0.1 m^2 quadrat per plot, drying at 60ºC for 48 hours and weighing. Stock were excluded from the trial plots until February 2014 to ensure all species had adequate opportunity to set seed, at which time 50 merino wethers (weighing approximately 60 kg) grazed the 2 ha site for two weeks. The site was grazed again in May for two weeks by the same mob of sheep, and finally in August for another fortnight before being removed on 1 September to enable the legumes to set seed at the end of year two. Plots were scored on 1 September for the percentage cover of the sown legume species by laying a 0.24 m^2 quadrat (divided into 380 squares, each 25 × 25 mm) in a representative area of each plot and counting the number of squares that contained the base of a sown legume. An assessment of aboveground biomass was taken in November 2014 and March 2015 by cutting herbage in one 0.1 m^2 quadrat per plot, sorting sown species from weeds, drying at 60ºC for 48 hours and weighing each component. Seedling regeneration was assessed on 4 May 2015 by counting the number of seedlings in a 1 m × 1m quadrat. ANOVA was conducted in Genstat and treatment differences were reported at $P < 5\%$.

Results

Rainfall received at the site during the establishment year was below average for all months post sowing (March 2013), other than June which received more than three times the monthly average (Table 2). The spring and summer of year 1 was dry with very low pasture growth equivalent to short term drought conditions. Breaking rains were received on 14 February 2014 followed by twice the monthly average in March. With generally well-timed rainfall events throughout the year including 145 mm rainfall in August, 2014 was one of the best pasture-growth years in three decades.

Table 2. Monthly rainfall (mm) recorded near the experimental site (Bureau of Meteorology station 070147) 2013-15 compared to the long term (55 year) median and average for that location

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2013	74.6	77.2	92.8	15.0	28.0	182.6	34.8	21.2	34.0	28.8	56.2	24.2	669.4
2014	13.0	113.8	114.8	57.6	42.2	51.8	17.4	145.8	40.0	50.0	18.2	154.4	819.0
2015	156.6	33.2	18.2	104.4	-	-	-	-	-	-	-	-	-
Mean	69.8	64.9	60.4	51.3	49.4	58.9	46.8	60.7	56.1	67.3	67.4	67.6	718.2
Median	54.2	52.4	48.0	34.2	37.4	48.7	41.0	51.0	47.0	60.0	64.0	53.8	702.8

All treatments established successfully with a high level of variability in initial seedling density, but above-ground biomass in spring of year 1was similar across treatments (Table 3). On 1 September 2014,

regenerated subterranean clover swards had achieved almost complete groundcover with crimson clover the only other species to occupy more than 50% of the sown area. The aboveground biomass of subterranean and crimson clovers at the end of spring in year two (2014) was double that of the next most productive legume, arrowleaf clover. All other legume species yielded less than arrowleaf clover, although differences with balansa and purple clovers were not significant (P=0.05). Weed biomass in year 2 was significantly less in the subterranean clover and crimson clover treatments, with legume DM yields higher in swards of those species. Significant rains in December/January (Table 2) prompted an early germination of some annual legume as well as weed species. Again, there was significantly less weed biomass in the subterranean clover and crimson clover swards at the end of summer 2014/15, corresponding with higher levels of legume biomass (Table 3).

Table 3. Seedling density (plants/m2), legume cover (%), legume and weed dry matter (DM; t/ha) of 8 annual legume genotypes sampled between 2013-15.

Sampling	Arrowleaf clover	Balansa clover	Biserrula	Crimson clover	French serradella	Purple clover	Subterranean clover	Yellow serradella	l.s.d. (*P*=0.05)
				Year 1; 2013					
Seedling establishment	97	270	294	77	192	152	173	117	(P=0.07)
Legume DM	5.4	3.4	5.5	4.6	5.2	3.6	4.2	4.0	(P=0.21)
				Year 2; 2014					
Legume cover (%)	11.7	28.3	10.7	59.7	25.1	16.5	92.2	38.0	14.02
Legume DM	3.0	1.7	0.5	6.3	1.3	2.0	7.0	1.6	1.35
Weed DM	3.6	3.6	4.3	1.1	3.8	2.8	0.3	3.6	1.86
				Year 3; 2015					
Legume DM	0.0	0.1	0.0	2.8	0.0	0.0	0.8	0.0	1.01
Weed DM	4.0	3.5	3.0	0.7	3.0	5.5	1.2	4.6	2.29
Seedling regeneration	101	124	1	263	2	5	573	15	144.7

The final density of regenerating annual legumes in year 3 was significantly greater in the subterranean clover sward compared to all other species (Table 3). Sampled during the first week of May, the seedlings of subterranean and crimson clovers were so large that individual plants were difficult to distinguish, reflecting the fact that they had been growing from as early as late December 2014. A small number of crimson clover flowers were evident at the time of sampling, indicating the mild autumn conditions the swards had experienced and the relative age of the seedlings. By contrast, seedlings of other species were at a very early stage of development. Density of biserrula, purple clover, French and yellow serradella was negligible in autumn of year 3.

Discussion

It is not possible in a preliminary experiment such as this to categorically attribute poor performance of a cultivar to any one factor. However, there are some obvious factors which were likely to have influenced the results. Seasonal conditions did not favour the harder seeded cultivars. The experimental period experienced one relatively dry summer (2013/14 - until mid-February) in the 12 months post-sowing, and one relatively wet summer in 2014/15 (Table 1). In both instances, the softer seeded cultivars were able to germinate on February and December rains, respectively, and compete with weed species. The ability to utilise opportunistic summer rainfall would seem to be an important adaptive trait for legumes in environments such as this which typically experience cold winter conditions that supress pasture growth and which receive over 50% of average annual rainfall between October and March (Table 2). Both Leura subterranean clover and Dixie crimson clover were able to respond to summer rainfall and compete effectively with weeds. Both species also happened to be those with the lowest levels of hard seed used in this experiment (Table 1). Even though Zulu II arrowleaf clover and Bolta balansa clover had over 100 seedlings/m^2 regenerate in May 2015 (year 3), those young seedlings were emerging amongst a dense mat of well-developed weeds such as sorrel (*Rumex acetosa*) which emerged on summer rainfall, and given the smaller plant size, their ability to out-compete the established weeds in the longer term seems unlikely.

Three of the four species which failed to regenerate adequately in year 3, biserrula, French and yellow serradella, were all species with a requirement for species of root nodule bacteria unlikely to exist in the background population at this site (see Table 1). Whilst N-fixation efficiency and rhizobia populations were not monitored in the current experiment, strain-host incompatibility with background rhizobium populations cannot be discounted as a factor contributing to the poor performance of these species. Biserrula is known

for its poor capacity to nodulate with a range of commonly available species of root nodule bacteria (Howieson *et a*l. 1995) and the negative effects of naturalised soil rhizobia on the formation of a successful symbiosis has even been recorded with *Trifolium* species such as balansa clover (Ballard et al. 2002). The site used for the present experiment had a history of subterranean and naturalised annual clovers for at least 4 decades prior to the establishment of the experiment and was, in this respect, similar to many Tablelands environments. This deserves further research.

The performance of French serradella may have been improved in the current study had we sown the softer seeded cultivar, Cadiz. There are few alternative cultivars of the other species with lower levels of hard seed which we suspect would assist their use and persistence in the Southern Tablelands. Over 30 cultivars of subterranean clover currently exist on the Australian market (Lattimore and McCormick 2012), providing a range of traits available to growers to cope with aspect, soil and climatic conditions. The lack of cultivar choice of the alternative legume species limits the ability to use a mixture of cultivars to guard against natural variability expected in a commercial permanent pasture situation.

Our results document the apparent failure of several new annual legume species under seemingly favourable seasonal conditions in this high rainfall environment, presenting a cautionary message to farmers and advisors to check the adaptation of new annual legume cultivars before planting them on a commercial scale. The results are perhaps unsurprising given that many of the cultivars of the alternative species were developed for lower rainfall and more Mediterranean climates. Their failure to persist at this site should not necessarily be interpreted as an inadequacy of the whole species, but rather a reflection of the fact that commercial cultivars of these species have not yet been developed for higher rainfall more temperate environments, highlighting a significant opportunity for future cultivar development. Subterranean clover is a species of Mediterranean origin, but has undergone decades of improvement which has led to the development of cultivars such as Leura which was selected for tablelands environments (Nichols et al. 2013). No doubt its disease resistance characteristics, its later maturing habit and low levels of hard seed have contributed to the superior performance of cv. Leura in this experiment.

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Life Cycle Assessment of grain cropping

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Abstract
Life cycle assessment (LCA) is a relatively recent framework that was developed to estimate the environmental impacts of industrial production processes and systems. The framework is now being applied to agricultural systems, including cropping systems, to identify opportunities for more environmentally-sustainable production. This purpose of this paper is to provide an overview of the application of LCA to grain cropping systems. Research at NSW DPI has focused on using LCA to estimate greenhouse gas (GHG) emissions from grain production systems for different regions of NSW as part of an industry-funded climate mitigation research program. The emission profiles suggest that GHG emissions in the systems modelled thus far are primarily the result of the production and application of synthetic N fertilizers, direct losses of nitrous oxide (N_2O) via denitrification of soil mineral N and dissolution of lime. The emissions intensities of crops also differ between regions primarily due to rainfall patterns and soil type, the type of fertiliser used, levels of inputs and yields. LCA, however, can provide a more holistic view of environmental impacts by also estimating effects on indicators such as eutrophication, land-use change and ecological toxicity. The reporting of numerous indicators allows potential perverse impacts to be assessed from applications of potential mitigation strategies. For example, increasing the proportion of legumes in a cropping rotation may reduce GHG emissions for that land area. However, the action may also result in land-use change to maintain supply of products displaced by including legumes in the rotation. Emissions associated with this land-use change such as sequestration or emission of soil or biomass carbon, may also affect the overall environmental impact.

Key words
Life Cycle Assessment, grains, environmental improvement, variability, indirect land-use change

Introduction

Life Cycle Assessment (LCA) is a framework originally developed to assess the environmental impact of industrial production systems, and to examine the effect of changes to the system. The application of LCA in recent years has included the assessment of the environmental impact of agricultural systems for the production of food, fibre and fuel (Harris and Narayanaswamy, 2009). As is indicated by the name, LCA usually examines the entire lifecycle of a product from production to disposal (cradle-to-grave). However due to lack of control a farmer has on the fate of his produce once it leaves his farm, agricultural LCAs usually model a cradle-to-gate system. Data included in a cradle-to-gate grain crop model includes the production, transport and use of all inputs (e.g. herbicide, fertiliser, fuel) and the area of land required to produce the crop. Processing a LCA model produces indicators. Many indicators are available but commonly used indicators include climate change, human toxicity, ecological toxicity and eutrophication. These indicators are estimated from emissions to air, water and soil and emissions are generally calculated using emissions factors (EFs). Emissions factors are categorized as Tier 1 (global values, spatially coarse), Tier 2 (country- or region-specific, higher spatial and temporal resolution) and Tier 3 (highest resolution values resulting from modeling and comprehensive field sampling) (IPCC, 1997).

Where LCA is used to examine changes to a cropping system, indicators such landuse, water use and indirect land-use change (iLUC; Schmidt et al., 2015) also become important. For example, consideration of iLUC means that where a cropping system is altered to replace a cereal crop with a legume crop in a rotation, it assumes that land elsewhere is converted from pasture to cropland to ensure that supply of the cereal crop is maintained.

A LCA model generally examines the impact of producing a functional unit (e.g. a tonne of wheat at the farm gate). Where product mass is used as a functional unit, it is important to ensure that product quality is considered (Charles et al., 2006) as product quality determines the end use of the product. Ensuring quality is comparable is particularly important when using LCA to compare the impacts of different cropping systems.

A number of ISO standards relevant to LCA are available. ISO 14044:2006 deals with LCA processes including allocation and critical review, and ISO 14071:2014 provides additional guidance on critical review and reviewer competencies. Compliance with the ISO standards provides the rigour and transparency required for end users to have a high level of confidence in the results of the LCA study.

Results

NSW DPI researchers (Muir et al., 2014b, Muir et al., 2014a) have been using LCA to estimate the carbon footprints of crop and identify opportunities for GHG mitigation in NSW grain cropping systems. This work has shown that GHG emissions from the production and use of N fertilisers are the primary driver for the carbon footprint of wheat in north-west and south-east NSW (Figure 1), and that lime, where used, also makes a considerable contribution. On-farm GHG emissions associated with N fertiliser-use include direct losses of nitrous oxide (N_2O) via the processes of nitrification and denitrification, carbon dioxide (CO_2) from hydrolysis of urea when used and CO_2 from the dissolution of lime where used. Figure 1 demonstrates how the emissions profile of wheat can differ as a result of fertiliser type, yield, previous crop and region, noting that these four variables are dependent. Nevertheless, other research supports the key finding that N fertilisers make considerable contributions to the overall carbon footprint of crops (Barton et al., 2014, Biswas et al., 2008, Biswas et al., 2010, Brentrup et al., 2004, Wang and Dalal, 2015). Fertiliser N is also a key contributor to other indicators such as eutrophication, human toxicity and ecological toxicity (Figure 2) but can have a positive impact on land use through its positive effect on yield.

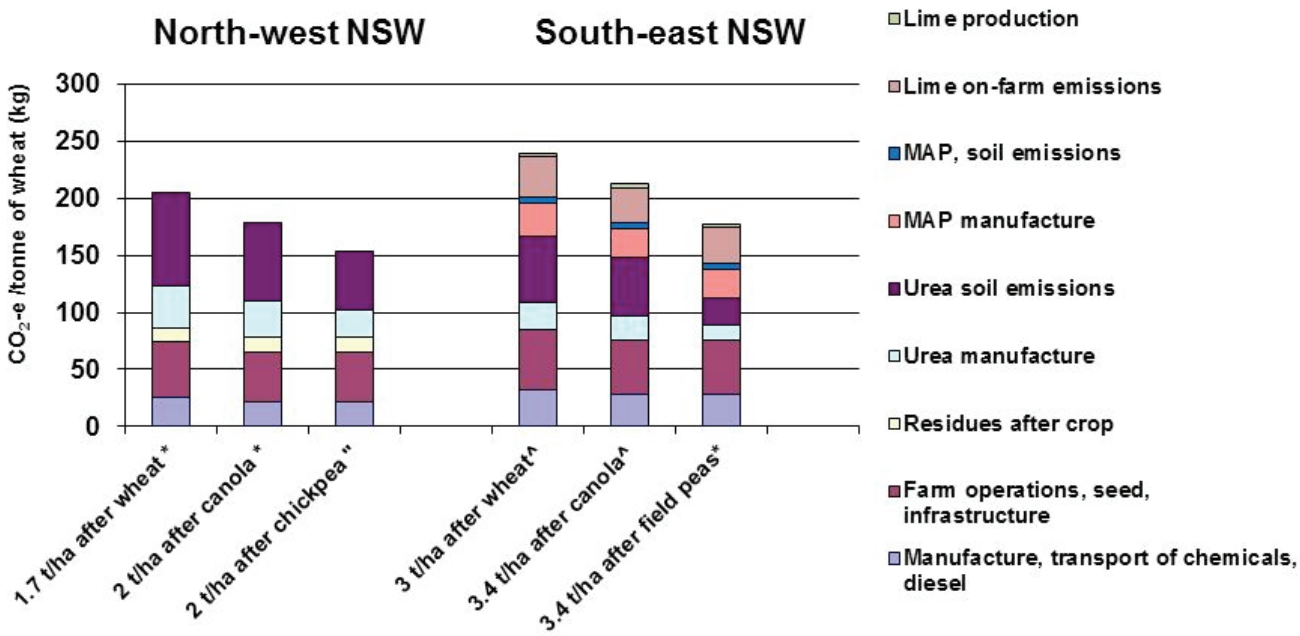

Figure 1. GHG emissions profile of short fallow wheat-wheat, canola-wheat and chickpea-wheat rotations in north-east and wheat-wheat, canola-wheat and field pea-wheat in south-east NSW. Labels followed by; * = 40 kg N/ha as urea applied, " 30 kg N/ha as urea applied, ^ 60 kg N/ha as urea and MAP, ' 40 kg N/ha as urea and MAP.

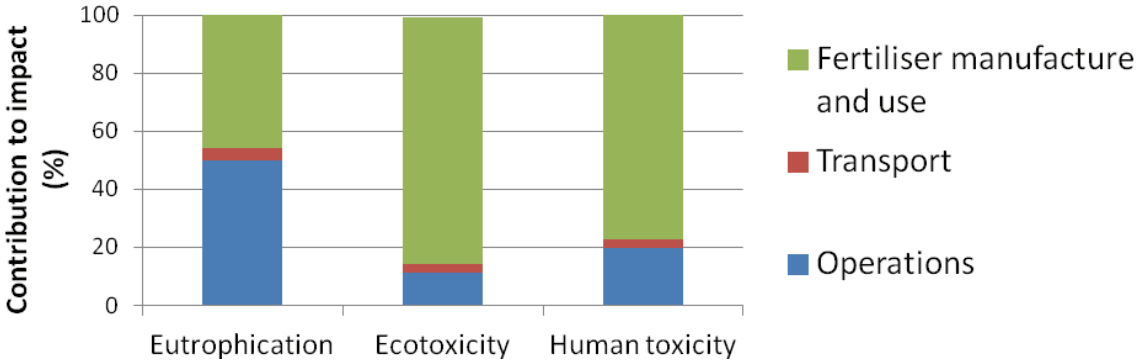

Figure 2. Relative contribution of fertiliser manufacture and use, transport of inputs and fuel, and on-farm operations to the LCA indicators eutrophication, ecological toxicity and human toxicity.

Discussion

A number of key challenges exist with respect to the application of LCA to grain cropping systems. Most LCA studies model the impacts of a representative system for a region of interest (Harris and Narayanaswamy, 2009); however management (e.g. fertiliser use) and biophysical parameters (e.g. rainfall) vary within a region. This means that the accuracy of LCA models based on a representative system for a region is limited. The uncertainty of outputs from these models comes from the impact of biophysical and management variables on emissions (MacKenzie et al., 1997, Mutegi et al., 2010, Chatskikh and Olesen, 2007) and yield. Potential exists to develop models that better explain the variability within a region using validated biophysical models (e.g. APSIM), statistical methods and spatial analysis. For example, numerous runs of biophysical models with different management and biophysical parameters could be conducted across numerous locations in a region. Data for emissions to air, soil and water, and yield could be extracted from the model runs and extrapolated across the region in ArcGIS based on biophysical layers to produce a distribution for each parameter of interest for the region. These distributions could then be used as inputs for Monte Carlo analysis to calculate the permutations of all combinations of the distributions. Using validated biophysical models would ensure perverse outcomes (e.g. high yield with low available N) are not calculated. The benefit of using an approach that provides a distribution of impacts, rather than a representative impact, is that it provides a probability of an impact occurring in the region and range of impacts that could be expected.

iLUC is another important consideration when assessing changes to cropping systems designed to mitigate the impact of production. For example, Barton et al.(2014) concluded that biologically-fixed N in a legume-wheat rotation reduced GHG emissions 35% when compared to a wheat-wheat rotation. What was not considered in that study was the land required to grow wheat to ensure wheat supply did not change. Ignoring this effect implies that the wheat supply is maintained without any changes to existing land uses and that is not possible. Much work has been done in recent years on developing models to account for iLUC in response to changes in agricultural systems (Schmidt et al., 2015). An iLUC model would consider that the displaced wheat would be grown on crop land converted from permanent pasture. This conversion can release large amounts of CO_2-e through the loss of soil organic carbon. Research (Murphy B, 2012) suggests that converting permanent pasture to cropping in the mixed farming region of NSW could release as much as 130 t CO_2-e ha^{-1} from the loss of soil organic carbon. This change would negate some or all of the GHG savings from introducing legumes into a crop rotation.

Background data that comes from databases is often used to build LCA models. Much of this data is derived from processes in Europe and North America. Potential exists to improve these data by examining systems relevant to grain crop systems. For example, current models for fertiliser production use modified data from European plants whereas the actual fertiliser used in Australia is predominantly made in Australian plants. Obtaining data on energy use and by-products from Australian fertiliser production plants has the potential to vastly improve the accuracy of LCA models of Australian grain crops and is important as fertiliser emissions make a considerable contribution to the overall emissions profile of crops (Figure 2).

Conclusion

LCA has proven to be a useful tool for the assessment of the environmental impacts of grain cropping. Results suggest that mitigation of these impacts will revolve around a reduction in the use of N fertilisers. Possible strategies include precision N management, the use of nitrification inhibitors, the inclusion of more N fixing legumes in rotations and/or variable rate technology for N and/or lime applications. More work needs to be done, however, to ensure that LCA models of regional grains systems represent the diversity of management and biophysical variables that exist. Any models also need to consider indirect effects of management decisions, such iLUC, to ensure these impacts are well understood.

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Greenhouse gas mitigation potential and profitability of practices on Australian grain farms

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Abstract
Australian farm owners are being encouraged to mitigate emissions of greenhouse gases such as carbon dioxide (CO_2) and nitrous oxide (N_2O). However, trade-offs exist between mitigation strategies as practices that sequester carbon (hence reducing CO_2 emissions) may increase N_2O emissions. Further, the amount of CO_2 (via carbon sequestration) or N_2O emitted may change with time and vary with location characteristics including weather and soil type. In this study the net global warming potential and financial effect of on-farm practices designed to abate greenhouse gas emissions was assessed for a case study farm in the Western Australian wheatbelt (low carbon soil-low rainfall environment). The usual farm management formed the baseline against which alternative scenarios aimed at mitigating greenhouse gas production were evaluated for a 100 yr period. Simulated yield and nitrogen fertiliser rates from the APSIM model were used to estimate the annual gross margin. Scenarios that involved retention instead of burning stubble or adding additional organic matter decreased the net global warming potential without reducing gross margins. Scenarios that used a lower nitrogen fertiliser rate than the baseline resulted in a decrease in yield and profitability with little effect on net global warming potential.

Key words
Greenhouse gas abatement, APSIM, economic analysis

Introduction
Under the new Emissions Reduction Fund policy, Australian farm owners can be paid for greenhouse gas abatement if they bid the least cost delivery price through a reverse auction process. Farm owners therefore need information about the effect of practices on soil carbon and N_2O emissions, productivity and gross margins. However, trade-offs exist between mitigation strategies as practices that sequester carbon - thus reducing CO_2 emissions - may increase N_2O emissions. The potential trade-offs are not always obvious and may reduce the potential for Australian grains farms to mitigate GHG emissions. In addition, suitable mitigation practices may vary across regions, reduce whole farm profitability or fit poorly within farm management. To better understand these trade-offs, we estimated the net, whole-farm GHG mitigation balance and financial impact of various management practices applicable to Australian grains farms.

Methods
Case study farm
We established six representative farms in collaboration with farmer groups across the northern, southern and western grain growing regions of Australia. The usual cropping systems and management employed by the farmers were developed into a set of standard rules to support modelling with APSIM and formed the baseline for analyses at each farm. In this paper, we present results for one of the case study farms, located at Dalwallinu (30.27°S, 116.66°E) in Western Australia. Average climatic conditions include annual (winter-dominant) rainfall of 310 mm yr^{-1} and minimum-maximum temperatures of 16 to 36°C in summer and 6 to 17°C in winter. The most common soil types on the 6,000 ha case study farm are sands and sandy duplexes. For this study, simulations were made for a single representative soil (deep sand; 0.7% carbon in 0.0-0.1 m). The simulated farming system included three different rotations (Table 1) based on canola, wheat, barley, lupins and pasture combined with bare summer fallows. Simulated crops were sown between 25 April and 15 June after receiving accumulated rainfall of 10 mm within the previous 10 d; otherwise crops were dry sown at the end of the period. The amount of nitrogen (N) fertiliser applied to crops was calculated at sowing at the rate of approximately 40 kg N ha^{-1} per tonne of harvested grain based on average historical farm yields described by the collaborating farm owners. This target was met through a combination of nitrogen fertiliser supplemented with soil mineral N measured in the surface 0.1 m layer of soil at sowing.

Table 1. Crop rotations at the case study farm

Name	Crops in rotation (x denotes bare summer fallow in usual practices)
'Cereal'	Canola x wheat x wheat x barley
'Legume'	Canola x wheat x lupin x wheat x wheat
'Pasture'	Canola–weedy pasture during summer/winter/summer-wheat x wheat x barley

Scenarios

A set of alternative practices (Scenarios 2-9, Table 2) aimed at abating GHG emissions relative to usual practices (Scenario 1) was developed. Practices in the alternative scenarios were the same as for the Baseline except as described in Table 2. Simulated cowpea crops produced biomass > 1 t ha^{-1} approximately once every 5 years.

Table 2. Usual practices (Baseline, Scenario 1) and alternative practices (Scenarios 2-9) at the case study farm

No.	Name	Description
1	Baseline	Stubble burnt, bare summer fallow, weedy pasture in the pasture rotation
2	NoBurn	Stubble retained
3	Baseline+N	Stubble burnt, 125% of baseline N fertiliser rate
4	Baseline-N	Stubble burnt, 75% of baseline N fertiliser rate
5	NoBurn+N	Stubble retained, 125% of baseline N fertiliser rate
6	NoBurn-N	Stubble retained, 75% of baseline N fertiliser rate
7	Manure[1]	Stubble retained, 5 Mg ha^{-1} manure applied every 5 years, fully incorporated in 0.1 m topsoil
8	SummerCrop	Stubble retained, summer fallow green manure crop (cowpea) sown every year and sprayed out at end of February
9	ImprPasture	Stubble retained, winter legume crop (sprayed out at maturity) and bare summer fallows in place of weedy pasture

1 80% dry weight, 20% carbon, C:N ratio 30

APSIM modelling

All practices were simulated over 100 yr with the APSIM model (Holzworth et al., 2014; www.apsim.info) using Wubin climate data from the SILO database (Jeffrey et al., 2001). APSIM' performance in simulating baseline conditions and organic matter additions was evaluated by modeling a soil biology field experiment (http://www.liebegroup.org.au/trial-programs-3/) near the farm and other measurements for N_2O (Barton et al., 2013). Yield, soil organic carbon and nitrous oxide emissions were simulated in accordance with observations (data not shown).

Calculations

Amounts of carbon sequestered in the soil and N_2O emitted were converted to CO_2 equivalents (CO_2e) using conversion factors of 1 and 298, respectively (IPCC, 2013) to evaluate the global warming potential of different practices.

Economic analysis

Gross margins were calculated at the paddock scale as income (yield x average price received in the past 5 yr) minus variable costs (e.g. fertiliser, chemicals, fuel, manure) for each year across the 100 yr simulation. The gross margins were then averaged across each rotation to allow comparisons of profitability between rotations and across abatement scenarios. Economic data were sourced from the Department of Agriculture and Food Western Australia (DAFWA, 2012).

Results

Greenhouse gas emissions and net global warming potential

Soil organic carbon (Fig. 1a-c) increased by 0.12 to 0.24 % relative to baseline values in the scenarios where stubble was retained (Scenarios 2, 5 and 6). A further increase in soil carbon of around 0.04 to 0.08 % occurred when additional organic matter inputs from manure (Scenario 7), summer crops (Scenario 8) or improved pasture (Scenario 9) were added to these systems. There was little change in soil carbon relative to baseline values when stubble was not retained (Scenarios 3 and 4). Average N_2O emissions (Fig. 1d-f) were greater than the baseline (0.07 kg N_2O -N ha^{-1} yr^{-1}, consistent with field observations; Barton et al., 2013) in all scenarios unless nitrogen fertiliser applications were reduced (Scenarios 4 and 6).

The net global warming potential from combined changes in sequestered carbon and N_2O emissions was dominated by the changes in soil carbon (Fig. 1g-i).Soil carbon increased by 0.04-0.07% in the baseline scenarios and so net global warming potential was small (<5,900 kg CO_2e ha^{-1} for the simulation period) for the baseline. There was little difference in global warming potential between the baseline (Scenario 1) and other Scenarios where stubbles were also burnt (Scenarios 3 and 4). For scenarios where carbon was sequestered through retaining stubble or other additions from soil organic matter (manure, summer crops and improved pasture), the cumulative net global warming potential was reduced by 30-50 Mg CO_2e ha^{-1} over the 100 yr simulation period relative to the baseline values.

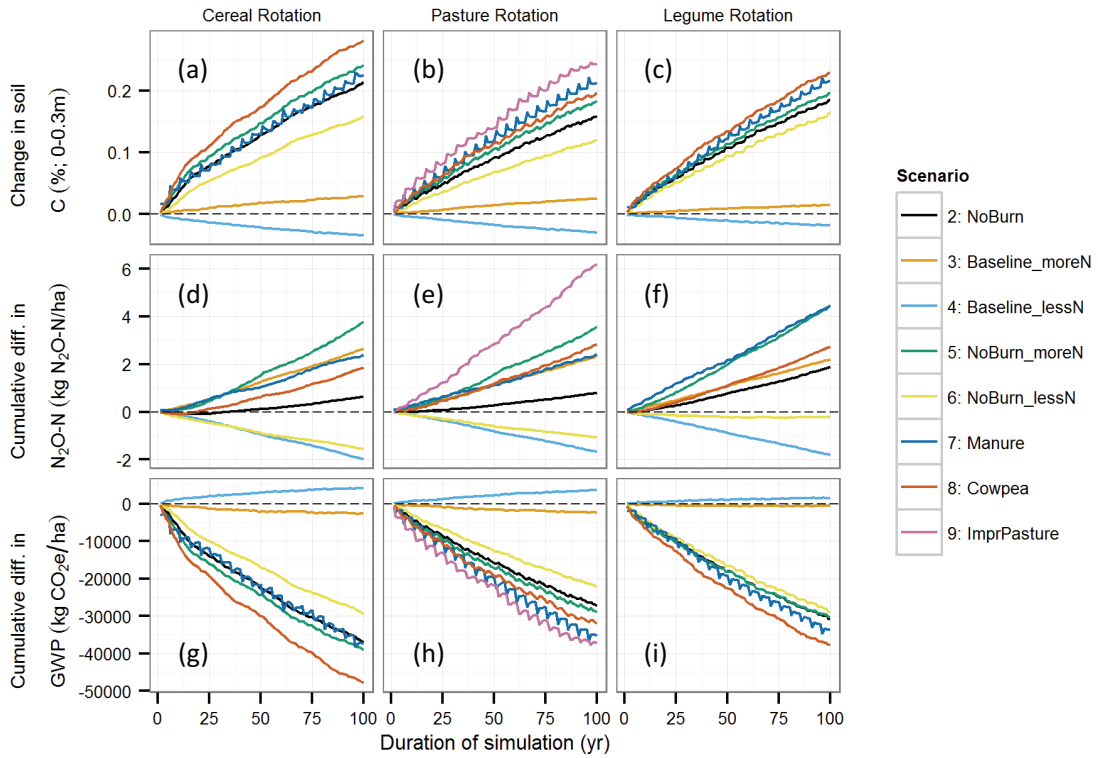

Figure 1. Differences in (a-c) soil organic carbon, (d-f) N2O emissions, and (g-i) net global warming potential between alternative scenarios (Scenarios 2-9) and farm usual practice (baseline, Scenario 1). Differences represent the accumulated annual difference during the 100 yr simulation period.

Yield

The median yield (e.g. for the cereal rotation, Figure 2) of all crops increased, and yield variability decreased, in response to applications of manure (Scenario 7). Median crop yields for canola, wheat and barley also increased in response to added nitrogen fertiliser (Scenarios 3 and 5) and decreased when nitrogen fertiliser was reduced (Scenarios 4 and 6). Wheat yields in the pasture rotation also increased in response to improved pasture (Scenario 9 in the pasture rotation; data not shown) but the yield of other crops in this rotation was not affected by inclusion of improved pasture. The use of a summer crop (Scenario 8) had little effect on the median yield of any crop but increased yield variability. The range and variability of crop yields in the cereal rotation (Fig. 2) were similar to those obtained in the pasture and legume rotations (data not presented).

Gross margins

The median and range in gross margins (Figure 3) for the different scenarios was closely related to values obtained for crop yields (Figure 2). The largest gross margins ($263-356) occurred when manure was applied. The median gross margin for improved legume pasture in the pasture rotation ($215) was greater than the baseline weedy pasture ($155) and delivered N savings to later crops. Crops in Scenarios 2, 3 and 5 had the same or a greater rate of N fertiliser and also had similar gross margins ($157-238 in the three rotations) to the baseline ($154-211). The median gross margin was lower for scenarios with reduced N fertiliser ($123-201 in the three rotations) or cowpea ($137-163). Thus the lower revenue from smaller crop yields (Scenarios 4-6) was not compensated by savings in fertiliser. For cowpea, more variable yields and the costs of cowpea management were not compensated by any savings in N fertiliser permitted by N added from cowpea.

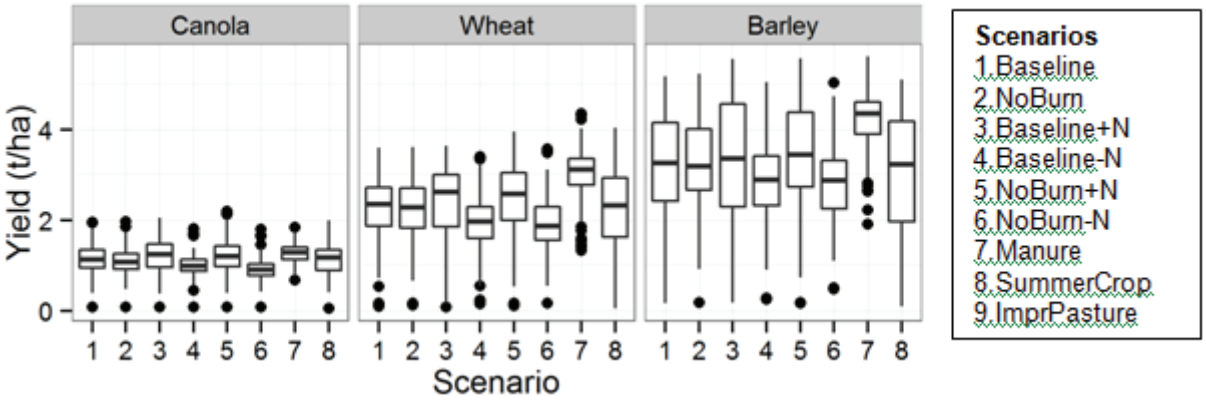

Figure 2. Boxplots (bars showing 1.5 x interquartile range) for yield of canola, wheat and barley in the cereal rotation. Plots represent the yields obtained in response to usual (Scenario 1) and alternative (Scenarios 2-9) practices (described in Table 2). Scenario 9 (improved pasture) was not applied in the cereal or legume rotation. Median values and variability of yields were similar to results obtained for the pasture and legume rotations (data not presented).

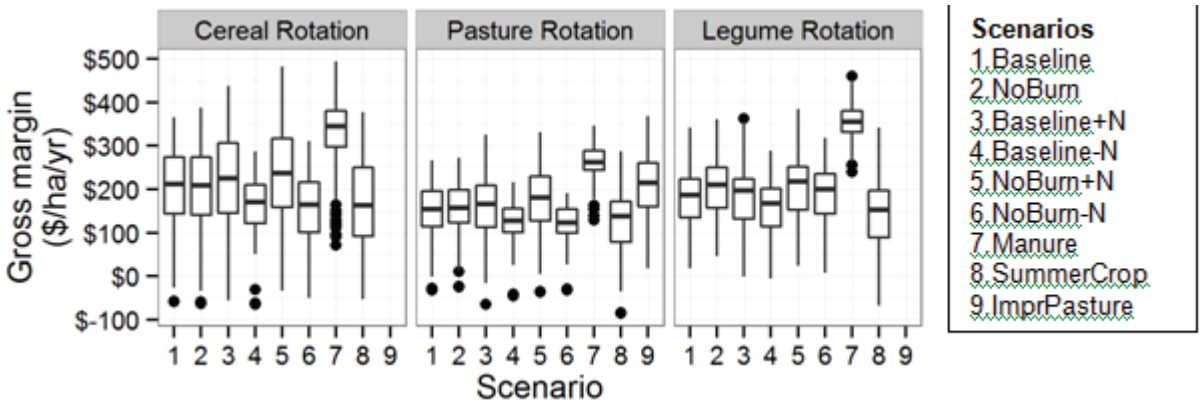

Figure 3. Average annual gross margins (bars showing 1.5 x interquartile range) for scenarios (described in Table 2) at the case study farm. Scenario 9 (improved pasture) was not applied in the cereal or legume rotation.

Conclusion

A number of practices were available to the case study farm which had potential to reduce net global warming potential relative to baseline practices. These practices were based on increasing soil carbon by retaining stubble or increasing inputs of other organic matter, and could be achieved without reducing gross margins. By comparison, reducing the amount of N fertiliser applied resulted in lower yield, lower profitability, and little change in or reduced carbon sequestration. The potential to increase carbon is limited for many Australian soils (Lam et al., 2013), and so this finding may be limited to situations such as this case study farm where initial soil carbon and typical N_2O emissions are both low. The applicability of these results to locations with higher N_2O emissions requires further investigation.

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N_2O mitigation opportunities in subtropical cereal and fibre cropping systems – a modelling approach

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Abstract
Agricultural crop and livestock production contribute 78 % to global anthropogenic nitrous oxide (N_2O) emissions. Therefore, mitigation of N_2O emissions from agricultural systems is important. In this study, the trade-off between crop yield and N_2O emissions in subtropical cereal and fibre cropping systems under various management practices was investigated to identify potential mitigation options. For this, the APSIM model was first tested against data from a field experiment on a vertosol comprising several irrigation treatments in subtropical Queensland. One soil hydraulic parameter and one parameter in the denitrification sub-model were calibrated against a subset of the data. The validity of the model was confirmed with the remaining data. For the six datasets we found a good correlation between measured and predicted yields (R^2 = 0.90) and seasonal N_2O emissions (R^2 = 0.49). Long-term scenarios were then calculated with the validated model. Long-term average yield and N_2O emissions both increased under increased nitrogen (N) supply from legumes or extra N fertiliser, and so, there was a trade-off between maximising yield and minimising N_2O emissions. N_2O emissions also increased when crop yields were limited due to water stress, because of increased mineral N availability. Given the annual variability in climate and soil nitrogen availability, mitigating N_2O emissions is not a simple task. A tool for proper yield forecasting could therefore be of great benefit for estimating the amount of nitrogen required and thus assist in managing N efficiently and in mitigating N_2O emissions.

Key words
Agricultural systems, simulation, greenhouse gas, wheat, cotton, vertosol

Introduction

Agriculture plays an important role in greenhouse gas emissions. About 60 % of global anthropogenic nitrous oxide (N_2O) emissions stem from agricultural production systems (Syakila and Kroeze, 2011). Of all global agricultural land 23 % are situated in the subtropics, and more than 15 % of the global N_2O emissions from fertilised land are emitted in the subtropics (Bouwman et al., 2002; Stehfest and Bouwman, 2006). Therefore, efficient N_2O mitigation strategies for subtropical cropping systems are needed, which also enable crop yields to be maintained or increased. To mitigate N_2O emissions, the environmental conditions under which high emissions occur, have to be understood. This can be achieved by monitoring N_2O emissions in crops under varying management practices and measuring relevant environmental factors driving the formation of N_2O at the same time. However, field experiments are constrained in management practices, locations and duration. So, process-based models are valuable supplements to extrapolate these experiments to a wider range of environments and management practices.

We used the agricultural systems model APSIM (Holzworth et al., 2014) to explore possible mitigation options for representative subtropical grain and fibre cropping systems by simulating long-term scenarios comprising various management practices. APSIM was calibrated and validated against data from a field experiment on a vertosol in subtropical Queensland.

Material and Methods

APSIM was calibrated and validated using data from a field experiment conducted on a vertosol at Kingsthorpe (27°30′44.5″ S, 151°46′54.5″ E) in the Darling Downs, Queensland. The experiment was conducted during a wheat-cotton sequence and comprised three treatments with varying irrigation intensities, summing up to six crop-treatment combinations (high (HI), medium (MI) and low irrigation (LI); Scheer et

al., 2013, 2012). N_2O emissions and water contents (0.0 – 0.4 m depth) were regularly measured, and crop yields were recorded at harvest. The model was set up with soil hydraulic parameters previously measured at the site (Kodur et al., 2013). A two-step calibration procedure was used. First, the parameter KL (d^{-1}) describing the maximum proportion of plant available water that can be extracted by roots in each layer per day was calibrated against yield from one treatment for each crop. Then the parameter $dnit_{lim}$, which describes the water filled pore space threshold above which denitrification occurs, was calibrated against N_2O emission measurements from one treatment. All other parameters were kept at their default values. For both yield and N_2O, the remaining four crop-treatment combinations were used for independently validating the model.

The validated model was used to assess possible N_2O mitigation options by simulating long-term (40 yr) crop rotations that involved varying fertilisation and irrigation management strategies. Two winter crop rotations (a wheat monoculture and a wheat-chickpea rotation) and two summer crop rotations (a cotton monoculture and a cotton-mungbean rotation) were simulated. In case of cotton, 90 % of residues were removed from the field while for the other crops residues were retained and crops drilled without tillage.

Results

Model validation

Water dynamics measured at 0.1-0.2 m and 0.2-0.4 m were well predicted (RMSE = 0.04 to 0.07 m^3 m^{-3}, data not presented). Yields (Fig. 1a) and seasonal N_2O emissions (Fig. 1b) were also accurately predicted for the validation treatments including different irrigation intensities and both wheat and cotton crops. Seasonal N_2O emissions were found to be very sensitive to the newly introduced parameter $dnit_{lim}$. This highlights the importance of accurately predicting the water dynamics, which this parameter relates to.

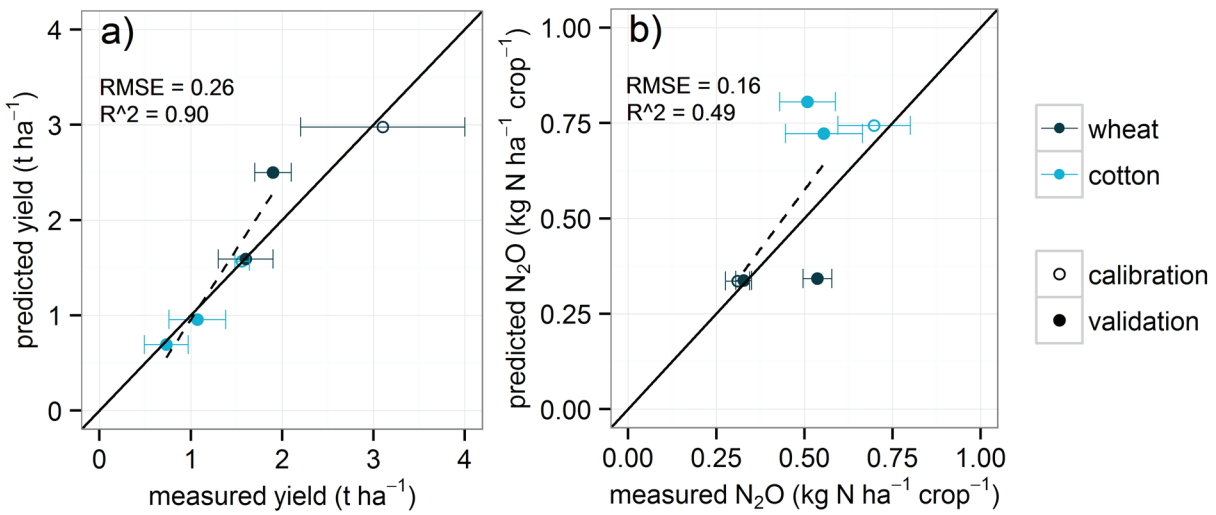

Figure 1. Predicted against measured (a) crop yields and (b) seasonal N_2O emissions for the calibration (dots) and validation (circles) data from the vertosol at Kingsthorpe. Standard deviation of the observations, 1:1 (solid) and regression lines (dashed) are shown. RMSE (root mean square error) and R^2 (coefficient of determination) are given.

Mitigation options

With respect to N-rate, two general relationships between yield and N_2O emissions were identified for the wheat and cotton monocultures in long-term scenarios (Fig. 2, left). Firstly, at low nitrogen (N) rates, e.g., up to 100 kg N ha^{-1} in rainfed crops, (small, closed symbols), both N_2O emissions and yields increased with increasing N rates. However, at N rates > 100 kg N ha^{-1} in the rainfed crops (large, closed symbols in Fig. 2), only N_2O emissions increased while yields remained constant. Split fertiliser application did not provide any benefit to yield or N_2O mitigation compared to applying all N at sowing (data not presented). For all crops, yields of irrigated crops (open symbols) were significantly higher than rainfed crops (closed symbols). Highest average yields under irrigation more than doubled compared to rainfed crops for wheat (Fig. 2, top) and tripled for cotton (Fig. 2, bottom). In wheat, N_2O emissions at high N rates were lower in irrigated than in rainfed crops. On the other hand, in cotton at all N rates and in wheat at low N rates, N_2O emissions were higher in the irrigated than in the rainfed treatments.

When a legume (chickpea or mungbean) was included in a crop rotation, maximum yields for wheat and cotton were reached at lower fertiliser N rates compared to the respective monocultures (Fig. 2). This provided savings of up to 50 kg N ha^{-1} per wheat crop in the irrigated wheat-chickpea systems. However, the maximum yield for rainfed wheat remained ~20 % smaller when in rotation with chickpea than under monoculture. Maximum cotton yields under rainfed conditions were ~30 % higher when in rotation with mungbean compared to the monoculture. There was no difference in the maximum yield of wheat or cotton crops grown in a monoculture or in rotation with a legume if the crops were irrigated. When a legume was included in the rotation in rainfed wheat, N_2O emissions were reduced by 3.0 kg N ha^{-1} yr^{-1} at an N-rate of 200 kg N ha^{-1}. However, at N-rates below 100 kg N $ha^{-1}$and in irrigated wheat there was no difference. In irrigated cotton, N_2O emissions were up to 0.8 kg N ha^{-1} yr^{-1} higher when mungbean was included in the crop rotation compared to the cotton monoculture.

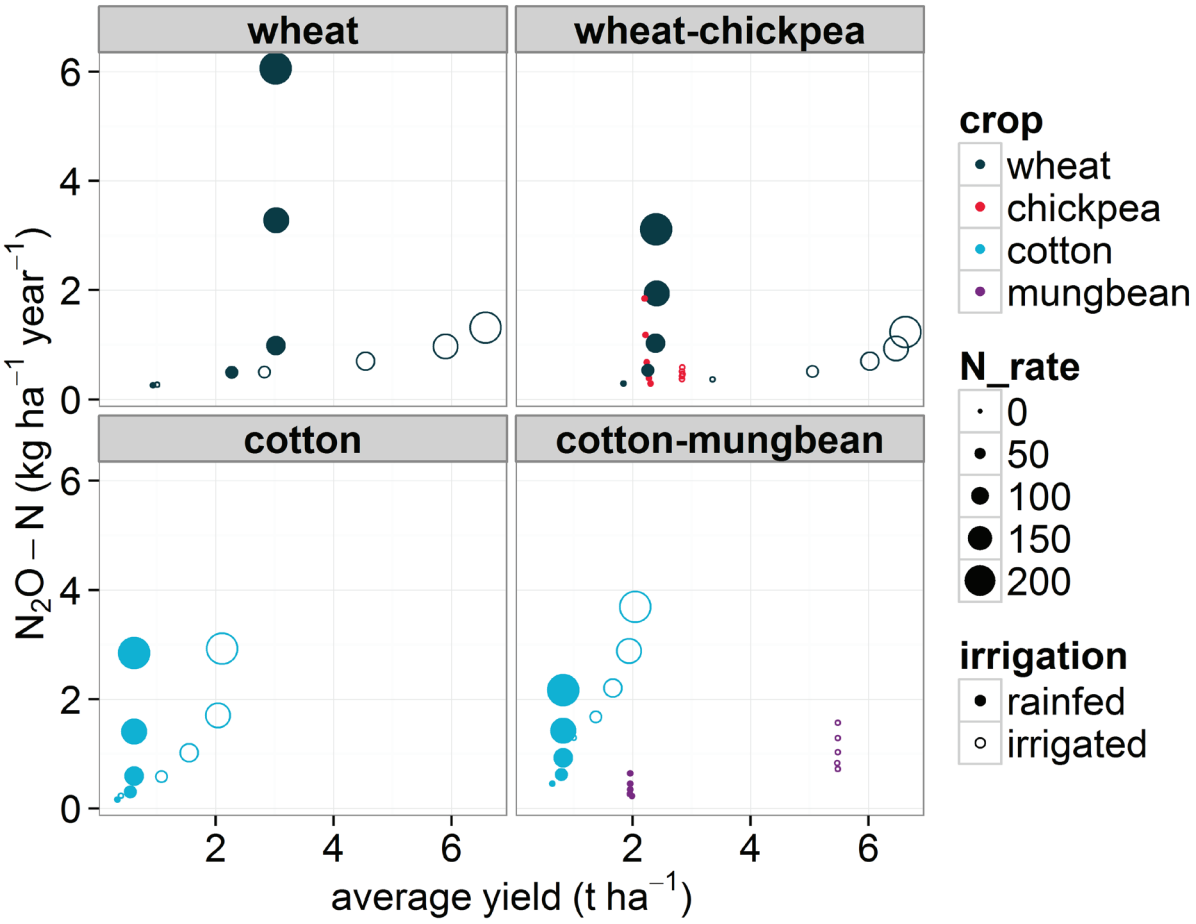

Figure 2. Trade-off between yield and N_2O emissions for four crop rotations simulated on the vertosol at Kingsthorpe. Nitrogen was applied at five rates: 0, 50, 100, 150 and 200 kg N ha^{-1} (size of bubbles) to non-legume crops. Irrigation was applied at two rates: zero irrigation (rainfed) and irrigation applied when plant available water in the upper 0.6 m of the soil was < 50% of plant available water capacity (irrigated).

Discussion

Model validation

Close prediction of yields and seasonal N_2O emissions in validation data (Fig. 1) confirmed the capacity of APSIM to reliably simulate these outputs with minimal calibration (i.e. calibrating only two model parameters). This justifies confidence in the capacity of the model to reliably simulate other treatments at the site and identify mitigation options by analysing long-term scenarios of a variety of management strategies.

Interactions between yield and N_2O emission in response to N and water availability

Two main interactions were identified from the modelled scenarios. The first finding was that there was a trade-off between increasing yield and minimising N_2O emissions at low N rates, while at high N rates a further increase in N input resulted in a negative outcome for both variables. These results are consistent with a yield plateau attained by crops at adequate N supply, while N losses continued to increase at higher N rates.

Our second finding of higher N_2O emissions in rainfed than in irrigated wheat under high N rates appears counterintuitive because soil moisture, an important driver for N_2O emissions, is generally higher under irrigation. However, this result occurred because water stress in the highly-fertilised rainfed wheat crops resulted in higher surplus N and higher soil N concentrations compared to the irrigated treatments. So there was more substrate available for denitrification in these crops. After high rainfall events this higher soil N led to a few large denitrification peaks each year which contributed the majority of N_2O emissions.

Mitigation options

There was high interannual variability of N_2O emissions and yields in the long-term scenarios. Hence, results from short-term experiments may not be representative of the long-term behaviour of these subtropical agro-ecosystems, and so simulation studies may be an important addition to field studies to gain insights into long-term emissions and mitigation options.

In this study, N_2O emissions were not caused by only one management factor (e.g. irrigation or fertilisation) but by the complex interaction of several factors. Hence, a holistic approach needs to be taken to identify strategies that mitigate N_2O emissions without compromising yield. Such strategies would utilise an optimal N rate for the current plant environment that would maximise yield and limit N_2O emissions, and thus maximise nitrogen use efficiency (NUE). Therefore, N fertiliser should be applied taking into account available soil N and expected yield. The latter strongly depends on available water, including soil water storage, expected rainfall and irrigation. Soil testing for mineral N in combination with weather forecasts and yield forecasting tools would provide great benefit in managing N application and thus optimising the dynamic trade-off between crop yields and N_2O emissions.

Acknowledgements

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The effect of variable nitrogen fertiliser rates on indirect nitrous oxide emissions and nitrate losses from furrow-irrigated cotton production

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Abstract
Nitrous oxide (N_2O) is a potent greenhouse gas and a key causal agent in the depletion of stratospheric ozone. Current measurements of agricultural N_2O emissions have focused on direct losses from the soil surface; yet, indirect N_2O emissions are thought to be 29 to 67% of direct losses. IPCC estimates of indirect emissions suggest that 2.8 to 25 g of N_2O-N may be produced per kg of NO_3-N lost. Within the Australian cotton industry, nitrogen fertiliser rates average at 250 kg N ha^{-1}, though higher rates are not uncommon. We present the findings from a pilot study comparing nitrate losses from furrow irrigated cotton under variable N fertiliser application rates (363, 463 and 563 kg N ha^{-1}); and use these to estimate indirect N_2O emissions. N rate had no effect on nitrate run-off loss. Significantly more nitrate was lost from skip than water furrows. Increasing plant internal nitrogen use efficiency, using irrigation methods which reduce lateral water flow through the soil profile, and/or placing fertiliser deeper or more asymmetrically within plant beds are likely to decrease nitrate losses and, consequently, indirect emissions. Further study examining losses across a greater range of N rates, and with variation in timing and methodology of N application are necessary to obtain a better understanding of the variables associated with indirect emissions.

Key words
Nitrogen fertilizer, greenhouse-gas, run-off, IPCC emission factor

Introduction

Over the last century, anthropogenic reactive nitrogen (N) production has increased over a-hundred fold from 15 Tg $year^{-1}$ in 1860, to 191 Tg $year^{-1}$ in 2005 (Galloway et al. 2008). Agriculture is the dominant source of N_2O emissions. Emissions from fertiliser use and manure management represent 26-35% of total N_2O sources (Butterbach-Bahl et al. 2013; Syakila & Kroeze 2011). One consequence, of increased N production and use, has been a 0.2-0.3% per annum increase in nitrous oxide (N_2O) production (Conway & Pretty 2009). N_2O is a potent greenhouse gas, with an equivalent 100 year warming potential 298 times that of carbon dioxide, and a key causal agent in the depletion of stratospheric ozone (Butterbach-Bahl et al. 2013). Most N_2O is produced as an intermediate product of two microbial processes, nitrification and denitrification. Rates of N_2O emissions are controlled by numerous environmental factors including soil porosity, temperature, soil moisture, organic carbon content, oxygen availability, microbial community, pH and mineral N availability (Eichner 1990). Variations in agricultural management practices, e.g. irrigation method and crop rotations, influence both the rate and magnitude of direct N_2O emissions, by altering the availability of substrates and the conditions required for nitrification and denitrification (Eichner 1990).

Within the Australian cotton industry, application of N is required to maintain the quality and magnitude of yields. Average N rates in 2012-13 averaged at 243 kg N ha^{-1}, ranging between 93 to 370 kg N ha^{-1} (Roth Rural 2013); though at present, higher rates are not uncommon. Over fertilisation with N is problematic. A comparison of internal N use efficiency (iNUE = kg lint/kg crop N uptake) between commercial and optimum N rates for cotton, derived from a long term N rate trial, suggests that between 2004-9, the industry over fertilised by an average 49 kg N ha^{-1} (Rochester 2011). Excess N is lost via erosion, leaching, run-off and denitrification. A study by McHugh et al (2008), in Emerald QLD, found that N losses from run-off range between 0.92 to 37.57 kg ha^{-1} from furrow irrigated cotton which received 250 kg N ha^{-1}; though this may not be representative of industry. Nitrogen lost via run-off may be converted downstream to N_2O.

Indirect N_2O emissions, those resulting from the movement of N from human sewage and from N leaching and runoff into aquatic environments (Reay et al. 2005), are thought to be 29 to 67% the magnitude of direct losses (Syakila & Kroeze 2011). There have been few studies quantifying the rate and magnitude of indirect

emissions. Indirect emissions are produced via the same mechanisms which occur in soil but within the water column and sediments (Harrison & Matson 2003). Nitrogen lost via run-off may be converted to N_2O downstream. Intergovernmental Panel on Climate Change (IPCC) estimates of indirect emissions suggest that 7.5 g of N_2O-N may be produced per kg of N lost via run-off and leaching (EF-5 of 0.0075) (IPCC 2006). Using the IPCC EF-5 and the data from McHugh et al, we could estimate indirect losses from cotton to range between 0.0069 to 0.281 kg ha^{-1}. Given the excess use of N fertiliser within the cotton industry, strategies minimising N loss provide potential mitigation options for indirect N_2O losses. We undertook a study to compare the effect of N fertilizer application rate on nitrate concentrations in run-off, and used this data to estimate indirect N_2O emissions. To the best of our knowledge, no studies have yet quantified indirect N_2O emissions in the Australian cotton industry.

Methods

Site selection and field set up

The N rate trial was conducted at 'Red Mill' farm in Moree NSW, Australia (29°24′S, 149°57′E) over the 2014/15 cotton season. The soil at this site is a shrink-swell grey vertosol. The site was managed with a back to back cotton rotation, under a commercial rate of 363 kg N ha^{-1}. The trial site was randomly divided into 9 plots (12 by 950 m) and each plot assigned a rate of 363, 463 or 563 kg N ha^{-1} (n=3). N was applied in split applications using a combination of methods (Table 1). Approximately 6.1ML ha^{-1} water was applied, using alternate furrow irrigation, over 9 irrigations (Table 1). Farm staff estimated 10 to 15% of water was lost as run-off; we used a conservative run-off loss of 10% per irrigation.

Table 1. Nitrogen rate trial field management summary for "Red Mill" for 2014/15: cotton was sown 24/10/2014. Variable N rates were applied 71 or 77 days after sowing to give final rates of 363, 463 and 563 kg N ha^{-1}.

Days after sowing	Irrigation No.	Water used (ML ha^{-1})	N rate (kg N ha^{-1})	N application method
- 4 months		-	150	Anhydrous ammonia
-14	PRE	1.4		
39	1	0.587	58	Water run, N26®[1]
59	2	0.587	62	Water run, N26®[1]
71 or 77		-	0, 100, or 200	Side dress, liquid spray N42®[2]
77	3	0.587	61	Water run, N26®[1]
89	4	0.587	32	Water run, N26®[1]
105	5	0.587		-
113	6	0.587		-
123	7	0.587		-
134	8	0.587		-

[1]N26® liquid urea at a concentration of 20-26% N

[2]N42® liquid N solution at a concentration of 42.5% N, as urea (50%), nitrate (25%) and ammonium (25%).

Sample collection and analysis

Where feasible, water samples were collected each irrigation. Samples were not collected for irrigations 2, 3, 4 and 6 due to operational challenges. Samples were collected from the head ditch, and 2m in from the tail end of one water and one skip furrow for each plot. Nitrate concentration was measured using a Merck RQ Easy® meter. Concentrations below 5mg L^{-1} were considered to be negligible and given a value of 0. Total nitrate lost per irrigation was calculated using run-off estimates. Cumulative nitrate run-off loss was calculated by summation of total nitrate lost per irrigation. Given that not all irrigations were sampled and that nitrate concentrations were obtained from point samples, it is possible that total N loss may differ to the numbers reported in this study. N_2O emissions were estimated using the revised IPCC EF-5 for agricultural losses of nitrate via leaching or runoff of 0.0075 (IPCC 2006).

Data analysis

Data was analysed using R (R Core Team 2014). Analysis of variance (ANOVA) was used to determine the effect of N rate, irrigation number and furrow type (skip or water) on nitrate losses using the model:

NO_3 loss = Irrigation number + N rate + Furrow type

The relative importance of each of the model components was then determined through decomposition of the model using the 'lmg' metric in the 'relaimpo' package (Grömping 2006).

Results & Discussion

On average, 2.40% of the total N applied, or 11.29 kg NO_3-N ha^{-1}, was lost as nitrate run-off across all plots (Table 2). Irrigation number ($p<0.001$) and furrow type ($p<0.001$), but not N rate, significantly affected variation in concentration of nitrate lost, with 55% of the variation in nitrate losses explained by the model (see methods); of this, 68.6%, 30.9% and 0.5% of the variation in nitrate run-off was explained by irrigation number, furrow type and N rate, respectively. Nitrate run-off losses were highest at the start of the season, with losses from the pre and first irrigations significantly greater than other irrigations (Figure 1). More nitrate was lost from skip than water furrows ($p<0.001$); water moves through the dry furrow beds into the skip furrows, carrying nitrate. Irrigation strategies which minimize lateral flow of water (e.g. drip irrigation) and/or movement of water through mounds; and varying timing and placement of N fertilizer application (e.g. deeper and asymmetrical, closer to the water furrow) may decrease nitrate loss (McHugh et al. 2008).

Table 2. Nitrate run-off loss (range and average cumulative loss) and estimated indirect N_2O emissions, under continuous cotton crop managed with variable N rates of 363, 463 or 563 kg N ha^{-1}. Run-off was estimated at 0.14 ML ha^{-1} for the first irrigation and 0.058 ML ha^{-1} for subsequent irrigations. Indirect N_2O emissions were estimated from nitrate concentrations using the IPCC EF-5 of 0.0075.

N rate (kg N ha^{-1})	Range NO_3-N loss (mg L^{-1})	Average cumulative loss of NO_3-N (kg ha^{-1})	Cumulative N_2O-N emissions (g ha^{-1})
Head ditch	0 – 9.26	1.23	9.19
363	5.20 – 172	7.25	54.3
463	6.78 – 172	12.8	96.2
563	7.23 – 201	13.8	103

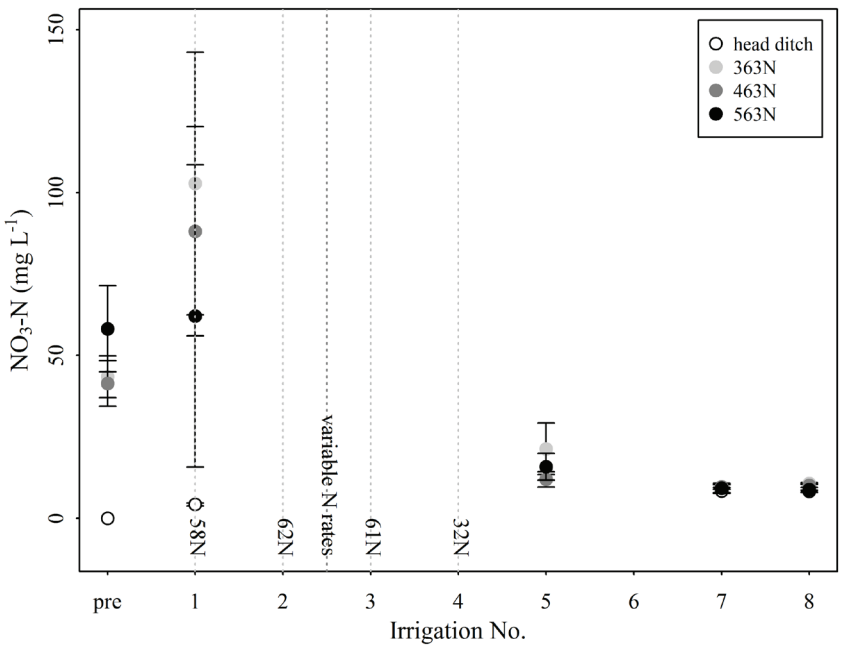

Figure 1. Nitrate concentration, with standard error, (mg L^{-1}) in run-off water from cotton fields fertilized with 3 different N rates (363, 463 and 563 kg N ha^{-1}). Vertical lines (···) represent in-season N (kg ha^{-1}) application.

There was no significant difference in nitrate losses under the different N rates. This was in contrast to what we expected, given 1) the positive relationship between direct N_2O emissions and N rates shown in other studies (e.g. Bouwman 1996; Gao et al. 2013); and 2) additional data collected from the first two irrigations from an N rate trial in Gunnedah NSW, with N rates of 200, 250 and 300 kg N ha^{-1} added pre-planting, which showed a significant, positive relationship between nitrate run-off and N rate (unpublished data). The discrepancy between our results and what we expected could be explained by the late application of variable N rates. In this study, and in another study measuring nitrate loss (unpublished data), we found that most nitrate loss occurred at the start of the season. Peak N uptake by cotton occurs around 80 to 100 days after planting, and plants which have greater access to mineralised N are able to assimilate higher amounts of N (Boquet & Breitenbeck 2000). Given variable rates were applied around 80 days after planting, effects due to N rates may have appeared as changes to cotton N nutrition. Alternatively, excess N may have been loss via other pathways rather than through run-off.

IPCC estimates of indirect N_2O emissions from tail water, for a single irrigation event, ranged from $3.90E^{-4}$ to $1.51E^{-2}$ kg ha^{-1}. The average cumulative emission from tail water, across all plots, was estimated at $8.46E^{-2}$ kg N_2O-N ha^{-1} (Table 2). Optimising NUE and reducing the industry's dependence on N fertilizers (e.g. biological N fixation), would minimize N loss and the resultant indirect emissions (Reay et al. 2012). There are a number of limitations associated with this study. In particular, IPCC estimates of indirect emissions may not be suitable for Australian cotton systems. The range of uncertainties for the IPCC EFs for nitrous oxide are from 0.0005 to 0.025 kg N_2O-N ha^{-1}; and result from variation in sampling conditions, microbial activity and on-farm practices (IPCC 2006). Whilst current IPCC emission factors for N_2O have been reduced (e.g. reduction in EF-5 from 0.025 to 0.0075), due to a lack of congruence between field measurements and EFs (IPCC 2006; Reay et al. 2005), the lack of data from within Australian systems mean that IPCC EFs are unlikely to provide good estimates within the Australian cotton industry. If we are to have a good grasp of indirect N_2O emissions, direct measurements of emissions across the whole irrigation network should be undertaken. Furthermore, our understanding of the temporal and spatial variation in N_2O production within furrow irrigation is limited. A better understanding of these variables would allow us to better estimate indirect losses within the industry and better shape proposed mitigation strategies.

Within this study, about 2.40% of N applied, was lost as nitrate run-off; which translated into an average indirect N_2O emission of 0.085 kg N_2O-N ha^{-1}. IPCC estimates of indirect emissions hold a large degree of uncertainty. Further work is required at broader temporal and spatial scales to better understand the processes associated with N_2O production and to quantify total indirect emissions from the Australian cotton industry.

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Potential for summer active grasses to minimise gaseous soil N losses

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Abstract
A replicated field experiment commenced in October 2013 at Meenaar, Western Australia, on a sandy duplex soil to compare the effects of summer chemical fallow with millet crops on soil nitrous oxide (N_2O) emissions. A closed chamber technique was used where the soil within and outside the chamber was wet uniformly with the equivalent of 40mm of rainfall over a 0.7m^2 area to initiate the anaerobic conditions that result in N_2O production. The net N_2O flux over the period of one hour was 4.4g N_2O-N ha^{-1} h^{-1} in the chemical fallow treatment, which was 40-42% higher than the rate observed in the millet treatments. The results indicate the potential for summer cover crops to reduce N_2O emissions in the short term. Further research is required to compare the total loss of N_2O in cropping rotations that replace summer fallow with crops.

Key words
Cover crop, denitrification, climate change, greenhouse gas

Introduction
Summer active grasses like *Panicum miliaceum* (cv. white French millet) dry out the soil over summer and may help to alleviate water logging, and deep drainage of soil water and nitrogen (Robertson et al., 2005). The growth of summer grasses might also minimize soil N losses that occur after summer rainfall as a consequence of nitrous oxide emissions. It has been proposed that drought tolerant grass cover crops will scavenge for available water and nitrogen in the soil over summer, thereby limiting the available energy source for bacteria that produce nitrous oxide gas (Dalal et al., 2003). This paper presents results for nitrous oxide emissions measured after treatments of 1) summer fallow with chemical weed control, 2) millet crops grown for 16 weeks and 3) millet crops grown for 21 weeks. The experiment is part of a four-year study, near Meckering in the central cropping region of south Western Australia, that is assessing the potential benefits of summer crops included in continuous wheat rotations.

Materials and methods
Site, soil and treatments
A four-year cropping experiment commenced in 2013 at Meenaar (116°86´E, 31°62´S) in the central cropping zone of south-east Western Australia. The soil surface was sandy with 59g/kg clay, 12.7g/kg total carbon, 9g/kg organic carbon, 1g/kg total nitrogen, 13mg/kg phosphorus (Colwell) in the top 10cm of soil. Most of the available mineral nitrogen (NH_4^+, NO_3^-) for plants was located in that layer. The clay content of the subsoil was generally higher than the sandy top, with between 59 g/kg clay and 159 g/kg clay from 10-30cm. The treatments commenced with the sowing of the summer crops on 25 October 2013, after a wheat crop was cut for hay and the site was sprayed with glyphosate (2l/ha Roundup Ultramax®) to kill weeds. The treatments were,

1. chemical fallow (CF) with weeds controlled with herbicides as required;
2. millet cover crop (MCC) killed early with herbicides after 16 weeks growth (5 weeks prior to soil N_2O sampling);
3. millet crop (MC) killed late by cutting and removing plants after 21 weeks growth (at the time when soil N_2O was sampled).

Each treatment was replicated four times in the experiment. Millet was sown with no-tillage knife-points on 0.22m row spacing with a seeding rate of 8kg/ha. Superphosphate fertiliser was also applied at a rate of 100kg/ha at seeding. The soil surface was wet at sowing (7.31% v/v, 0-12cm) following above average spring rainfall.

Field and laboratory activities

A closed chamber technique was used to compare the net flux of nitrous oxide (N_2O) in fallow and millet crop treatments on 26 March 2014. Two replicate gas sampling chambers were installed onto the soil surface, to a depth of 5cm, in each treatment plot the day prior the commencement of sampling. The mean height of each chamber above the soil surface was measured so that the volume of the chambers could be calculated. Any plants (i.e. millet or weeds) that were growing within the chamber area were removed by cutting them at their base, near to the soil surface, prior to the sampling. Nitrous oxide gas was sampled from the treatment plots in replicates 1 and 2 in the morning after 10a.m. and 3 and 4 were done before 3p.m. in the afternoon. The soil within and around each chamber was wet with 20 L of water uniformly applied over 0.7m^2 (equivalent to ~28mm rainfall). Sampling commenced immediately after the chamber lids were fitted (time zero) and then at 20 minute intervals until the lids were removed after the final sample (time 60 minutes) i.e. the chamber deployment period was 1 hour. The temperature inside each chamber was recorded over the sampling period using an iButton®logger suspended from the chamber lid. The extracted gases (25ml) were immediately transferred from a syringe into gas-evacuated 10ml glass vials (Agilent, USA), that had been sealed with aluminium crimp caps and butyl septa. Nitrous oxide concentration was estimated on a gas chromatograph (GC) system (7890-0505, Agilent Technologies, USA) with an electron-capture detector (µECD). Four soil cores (0-10cm) were collected with a hand auger from the wet area around each chamber and bulked together. The soil was dried in an oven at 45ºC for 48 hours and the amount of ammonium (NH_4^+) and nitrate nitrogen (NO_3^-) in each soil sample was tested at a commercial laboratory.

Estimation of net N_2O flux

Nitrous oxide flux was estimated as the change in concentration inside the chamber headspace over the chamber deployment time (i.e. 1 hour) using linear (LR) (Matthias et al., 1980) and quadratic (Q) models (Wagner et al., 1997). The models chosen were those that best suited the nature of the data points of a particular series (a "best-fit" approach) since linear models tend to underestimate the real fluxes, but quadratic models are less sensitive. Underestimation of the real fluxes can also occur when there are differences in soil properties in the treatments. Differences in soil air-filled porosity can effect gas exchange at the soil-atmosphere interface after chamber deployment (Liebig et al., 2012; Venterea, 2010; Venterea et al., 2009). The theoretical flux underestimation (TFU) was calculated in each treatment using the methods described by Venterea et al. (2010) to ensure that mean treatment fluxes were not artifacts of the imposed treatments.

Statistics

Differences in net N_2O flux in the treatments were calculated with a generalised linear mixed model (Genstat11th edition). The fixed parameter 'replicate' was included in the model to account for random effects. The log-normal distribution was used since the sample data was positively skewed (Venterea et al., 2009). Means were considered significantly different at $p \leq 0.05$.

Results

Treatment fluxes

Millet crop biomass was low (<500kg/ha) as a result of there being no in-crop rainfall in one of the driest summers for south-eastern WA on record. Nitrate nitrogen in the chemical fallow (NH_4^+, 0-10cm) was 13.2kg/ha which was higher than 9.4kg/ha and 6.6kg/ha after the millet cover crop and millet crop respectively (l.s.d. = 3.2, p=0.008). There was no difference in ammonium nitrogen (NO_3^-, 0-10cm) in the treatments. The net flux of nitrous oxide (Figure 1) in the chemical fallow was 4.4g N_2O-N ha/h compared to ~2.6g N_2O-N ha/h in both of the millet treatments (p=0.038). There was no effect of killing the millet after 16 or 21 weeks.

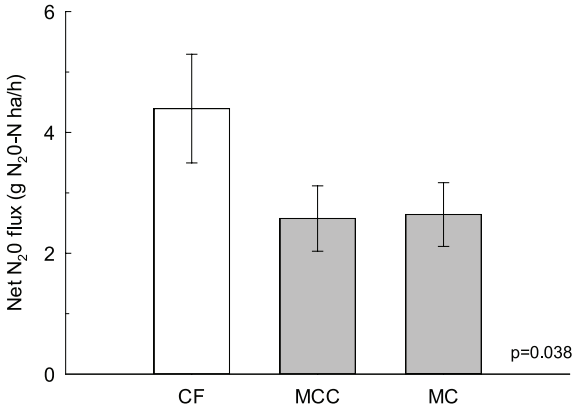

Figure 1. Comparison of the net nitrous oxide flux observed in late March in a chemical fallow (CF) a millet cover crop (MCC) killed early 5 weeks prior to sampling and a millet crop killed late on the day of sampling.

Discussion

The mechanism(s) driving N2O emissions

In a very dry summer, the crops used soil water and acquired available nitrogen for growth. It follows that there was less nitrogen in the soil surface compared to the chemical fallow where weeds were killed as early as possible with herbicides to conserve water and nitrogen. There was 40-42% higher nitrous oxide flux observed in the summer chemical fallow treatments than the millet plots. In this dry year, with low millet biomass production, the duration of millet crop growth had no effect on nitrous oxide flux. Lower flux rates with summer crops might be explained by less soil N assimilated by denitrifying bacteria in anaerobic soil conditions. However, other drivers of soil N_2O emissions like the availability of carbon in the soil also need to be considered. Sowing summer crops does incorporate some crop residues into the soil, potentially increasing residue decomposition rates compared to fallow. The presence of summer crop roots may also influence the abundance and activity of soil micro and macro flora.

A fit for cropping systems?

To confirm a net benefit from cropping systems that include summer crops, N losses (including other N loss pathways) would need to be quantified over longer periods of time e.g. subsequent N losses through leaching and into the atmosphere through the decomposition of the summer crop residues. Improvements in soil fertility over the longer term, from the addition of summer crop residues each year, might result in higher N_2O emissions after summer rainfall. The justifications for farmers to undertake changes in management should be aligned with their farm production e.g. N_2O emissions in relation to crop productivity (Van Groenigen et al., 2010). For example, summer crops could help to minimise emissions after rainfall and also serve as beneficial break/cover crops that improve the yields of winter crops in continuous cereal rotations (Krupinsky et al., 2002; Krupinsky et al., 2007).

A fit for the agricultural landscape?

The total emissions of nitrous oxide that have been measured from cropped soil in WA are low comparative to other cropping regions with higher rainfall in southern and eastern Australia (Barton et al., 2008; Barton et al., 2013). However, there are regions like the southern cropping zone, closer to the coast, of WA that are more likely to experience frequent and high summer rainfall.

Conclusions

Replacing fallowed land over summer with cover crops shows promise as a method to minimise soil N losses through nitrous oxide emissions. The extent of the benefits will depend on the frequency and amount of summer rainfall. Further work is required to quantify N losses over a longer period to confirm a benefit for cropping systems and climate change mitigation.

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High nitrous oxide emissions from irrigated maize and barley in northern Victoria

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Abstract
Nitrous oxide (N_2O) emissions from agriculture are problematic from both a productivity and environmental perspective, representing the loss of a valuable nutrient and emission of a potent greenhouse gas. Key factors driving N_2O loss include high soil water (a surrogate for anaerobic conditions), soil mineral N availability, labile carbon and soil temperature. Given the likelihood of regular waterlogging and high rates of N fertiliser applied, the potential for N_2O emissions from irrigated cropping systems was assumed to be high. A trial (two replicates) was established in December 2013 to compare N_2O emissions from an irrigated maize crop grown under two rates of N fertiliser (265 and 360 kg N ha^{-1}). Fertiliser was applied throughout the season using a variety of methods including: banded at sowing, with irrigation water and topdressing. A second trial established in April 2014 measured N_2O emissions from irrigated barley grown on either wheat or faba bean stubbles. Measured emissions from both sites were extremely high (peak fluxes >2 kg N_2O-N $ha^{-1}day^{-1}$) following irrigation early in each season; possibly associated with re-wetting of the soil at a time when crop uptake of N would be lowest. Treatment differences were generally limited except for selected periods when emissions from faba bean stubbles were higher than wheat. The substantial emissions of N_2O measured highlights the significant greenhouse risk associated with these systems. This paper discusses these results including potential implications for reducing emissions in farming systems with high N input requirements which undergo regular waterlogging.

Key words
Nitrous oxide, irrigated cropping, nitrogen, barley, maize

Introduction
N_2O is a potent greenhouse gas with a global warming potential approximately 300 times that of carbon dioxide. The major source of N_2O in Australia is agricultural soils, representing 23% and 3.6% of the agricultural sector and national greenhouse footprints, respectively (Department of the Environment, 2014). While there are a complex range of microbial processes associated with the production and consumption of N_2O (Butterbach-Bahl et al, 2014), nitrification and denitrification are typically identified as the main contributors to N_2O release. The largest emissions of N_2O are typically associated with denitrification. Denitrification occurs when microbes within the soil utilise NO_3^- as an alternative electron acceptor in the absence of oxygen, reducing NO_3^- to di-nitrogen (N_2) with N_2O produced as an intermediary. Due to the requirement for anaerobic conditions, denitrification is usually associated with periods of waterlogging. Consequently, soil water filled pore space (WFPS%) is often used as a surrogate for such conditions with the ratio of denitrification to N_2O nominally peaking at approximately 60%. Nitrification occurs at WFPS of approximately 4060% and denitrification to N_2 at >70%, increasing progressively to 100% (Granli and Bøckman, 1994). N_2O fluxes have also been shown to be highly responsive to rewetting of dry soils when increased microbial respiration depresses oxygen levels, inducing anaerobic conditions (Ruser *et al*., 2006).

Agricultural soils which undergo regular wetting and drying cycles are at significant risk of N_2O loss where other factors such as availability of mineral N, labile carbon and soil temperature (all key contributors to the processes outlined above) are nonlimiting. It therefore follows that the irrigated cropping systems of northern Victoria, characterised by regular waterlogging, wetting and drying cycles and high rates of N fertiliser application, are at significant risk of N_2O loss. Mitigation of N_2O loss is often based upon better synchronising N supply with crop demand through altered rate, timing, placement and form of application; often termed the four R's approach (IPNI, 2015). Given the high yield potential and correspondingly high N input requirements of irrigated cropping systems, achieving the four R's is particularly important. During 2013/14 two demonstration trials were undertaken in northern Victoria which aimed to quantify

the magnitude and seasonal dynamics of N_2O loss in such systems. This paper presents these results in the broader context of managing N_2O loss in high intensity irrigated production systems.

Methods

Site establishment and experimental design

In December 2013 a demonstration scale trial (2 replicates) was established within a commercial paddock at Koorop in the northern Victoria irrigation region to compare N_2O emissions from an irrigated maize crop grown with varying rates of N fertiliser inputs (265.5 kg N/ha and 360.5 kg N/ha). N was applied at sowing as a mixture of DAP and urea; further applications of N to the low N treatment were applied with irrigation water and the balance being applied as topdressed urea for the high N treatment. In April 2014 a second trial (2 replicates) was established within a commercial barley paddock at Kerang, also in the northern Victoria irrigation region. This site was part of a broader crop sequencing trial enabling a comparison of N_2O emissions from irrigated barley grown on either faba bean or wheat stubbles. N was applied as topdressed urea. Timing and rates of irrigation and fertiliser application are outlined in Table 1

Table 1. Irrigation and N applied to low and high N treatments for maize grown at Koorop, December 2013 to March 2014 (left). Irrigation and N applied to barley grown on either wheat or faba bean stubble at Kerang during 2014 (right).

*Further irrigation and N was applied outside the N_2O monitoring period (total of 2 ML/ha and 25 kg N/ha).

Timing	Irrigation applied (ML/ha)	N applied (kg/ha)		Timing	Irrigation applied (ML/ha)	N applied (kg/ha)	
		Low N	High N			Wheat stubble	Faba bean stubble
12-Dec 13	1	138	138	9-Apr 14	2	20	-
30-Dec 13	0.6		25	30-Jun 14	-	50	50
14-Jan 14	0.6	42.5	42.5	23-Jul 14	-	50	25
29-Jan 14	0.6	42.5	77.5	25-Aug 14	1	-	-
10-Feb 14	0.6	-	35	18-Sept 14	0.8	-	-
25-Feb 14	0.6	42.5	42.5	13-Oct 14	0.8	-	-
Total	4.0*	265.5	360.5*	Total	4.6	120	75

Monitoring for N_2O flux

Nitrous oxide measurements were taken using static chambers (Harris *et al*., 2013) with duplicate chambers placed in each plot. Samples were collected from the chamber headspace over a period of one hour (three samples) on each sampling event. Air temperature within the chambers was measured at the time of sampling and lids were removed from the chambers between sampling days. Samples were analysed by gas chromatography. Sampling was undertaken on a total of 18 days for the maize site (between 12-Dec 2013 and 4-Mar 2014) and 12 days for the barley site (between 9-Apr and 20-Oct 2014). Sampling was organised into clusters of three days designed to coincide with irrigation, fertiliser applications and or rainfall events, with sampling undertaken prior to these events, 1-4 days later and then 1-2 weeks after the event. The purpose of this sampling regime was to identify the general trend in emissions across the season and to capture peak fluxes in response to altered soil water/ anaerobicity and or mineral N supply. Fluxes were calculated from the linear increase in gas density within the chamber headspace over time after being adjusted for chamber volume.

Results

N_2O emissions from irrigated maize in response to varying N fertiliser rates

Measured daily N_2O flux rates at Koorop were extremely high (in some cases > 2kg N_2O-N/ha/day) early in the maize growing season following irrigation events (Figure 1). In subsequent days (typically 6-7 days), fluxes fell to <20 g N_2O-N/ha/day. Over the season, emissions trended strongly downwards, with the most extreme events associated with initial re-wetting of the soil at sowing. The relationship between N application rate and N_2O flux was not consistent, characterised by high variability with the lower N rate sometimes resulting in higher daily flux rates contrary to expectation. We hypothesise that this observation may be indicative of the two N rates tested being relatively similar, particularly early in the season when the

highest fluxes were measured. Given the demonstration focus of this trial, key measurements (soil mineral N, soil water, labile carbon) were not taken, thus the mechanism cannot be resolved.

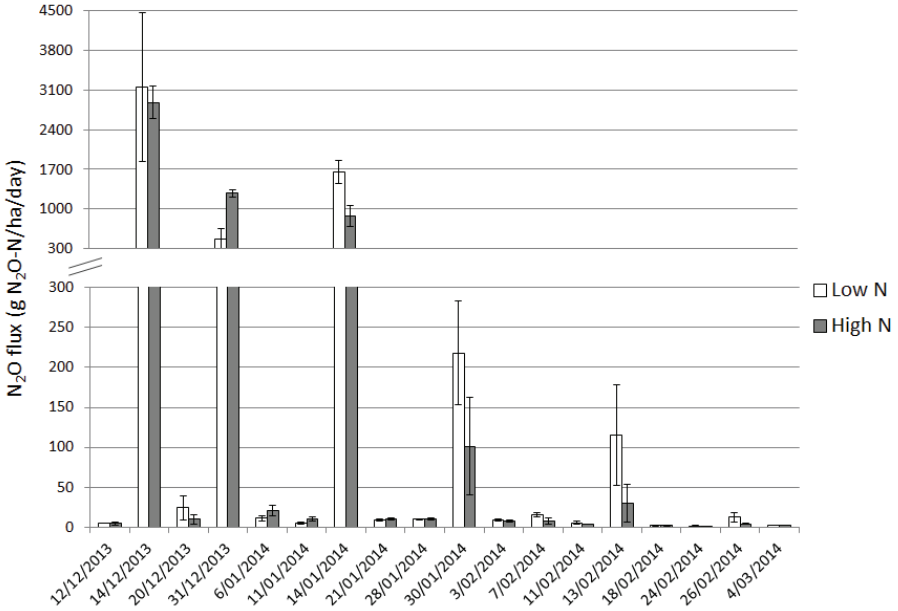

Figure 1. N_2O flux from maize grown at Koorop with varying rates of N fertiliser December 2013 to March 2014. Bars represent standard error.

N_2O emissions from irrigated barley in response to varying previous crop

Daily N_2O flux rates at Kerang were also extremely high early in the barley growing season (in some instances >2 kg N_2O-N/ha/day). Similar to the irrigated maize site, rates of N_2O emissions were strongly related to irrigation events. With the exception of the initial spike in emissions following irrigation at sowing, peak fluxes tended to be lower for the rest of the season (Figure 2). Fluxes from the faba bean treatment were generally higher than those from the wheat stubble. Soil testing on 12-July indicated significantly higher (84 kg N/ha versus 37 kg N/ha) mineral N from 0-60cm depth. While this data was not measured exclusively from the topsoil, where the majority of N_2O producing activity would be expected, it nonetheless illustrates a significant increase in mineral N from mineralisation of faba bean residues. It was expected that N_2O flux was limited by reduced availability of mineral N in the wheat stubble treatment despite the addition of extra N fertiliser. The difference in N application rate between treatments was moderate with the wheat stubble receiving 120 kg N/ha versus 75 kg N/ha for the faba bean stubble.

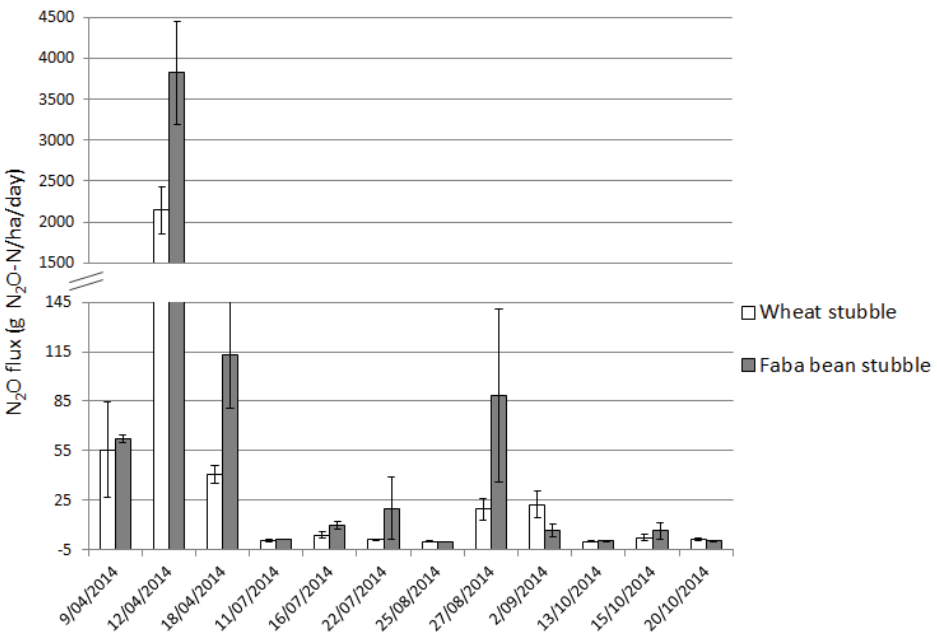

Figure 2. N_2O flux from barley grown at Kerang following either barley or faba beans in the previous winter season. Bars represent standard error.

Implications of these findings for future research and the irrigated cropping industry

The magnitude of N_2O fluxes measured following early season irrigation events highlights the significant greenhouse gas emissions associated with irrigated cropping systems. Ruser *et al*. (2006) also observed significant N_2O flux following rewetting of dry soils with small N_2:N_2O ratios at WFPS of up to 90%, indicating large scale incomplete denitrification (N_2O rather than N_2). It was suggested that these initial spikes may have been related to stimulation of microbial activity, leading to increased O_2 consumption causing anaerobic conditions favourable to denitrification. Furthermore Letey *et al*. (1980) measured low N_2:N_2O ratios immediately following rewetting which fell significantly over a period of 8 days. It was suggested that a possible explanation for this was a mismatch between the time taken for initiation of NO_3^- reduction and the production of N_2O reductase (the enzyme responsible for reducing N_2O to N_2).

Our findings pose a significant challenge to policy makers and industry in relation to irrigated cropping systems. On the one hand, high productivity demands significant N and water inputs, often early in the season. Conversely our data suggests that this can produce significant environmental risk. The question is whether there are feasible options to 1) decrease the N_2O effect of initial rewetting and 2) better match N supply to crop demand. Tools and products are available to slow N cycling within the soil (e.g. enhanced efficiency fertilisers), but predicting N supply from mineralisation to fine tune fertiliser rates remains a challenge. Managing the risk of rewetting appears to be more difficult; one option might be to avoid irrigating at sowing, halting germination until rainfall is received and delaying irrigation until later in the season when the soil is already moist. This an unlikely option for summer crops given that long term median rainfall at Kerang is approximately 15 mm/month during summer (BOM, 2015) and also contradicts the need for early sowing to achieve high productivity. There are few easy answers when trying to manage N_2O loss from intensive industries where small mismatches in water and N supply can result in significant emissions.

Conclusion

Nitrous oxide emissions measured as part of these demonstration focussed trials have highlighted a significant greenhouse gas risk from irrigated cropping in Victoria, in particular associated with early season irrigation events. Mitigation through manipulating availability of mineral N was attempted, but in the limited examples tested, adding extra N fertiliser did not necessarily result in higher emissions. However this was likely complicated by the relative similarity of N rates tested. The sheer magnitude of emissions measured following irrigation early in each season poses a significant challenge to both researchers and the industry to find ways of avoiding such high fluxes while maintaining the high levels of productivity associated with irrigated cropping.

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Cotton production in a changing climate

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Abstract
Daily outputs from the CSIRO Conformal Cubic Atmospheric Model driven by four general circulation models were used in a stochastic weather generator, LARS-WG, to construct local climate scenarios for key cotton production areas in eastern Australia. These scenarios along with elevated CO_2 concentration were then linked to a cotton model (OZCOT) to quantify their potential impacts on cotton lint yield, water use, and water use efficiency (WUE) under irrigated and rain-fed conditions in 2030. For irrigated cotton, we considered nine cotton production locations. For rain-fed cotton, we considered three planting configurations and four locations. Analysis of irrigated cotton (non-limiting water and nitrogen supply) in a changing climate showed that crop water-use would change from -3.4% to +2.7%; lint yield would change from -8.2% to +0.5%, and WUE would change from -11.0% to +2.1% across locations. For rain-fed cotton, future climate scenarios would increase cotton water-use by 3% to 6% at Emerald and Narrabri and decrease cotton water-use 5% to 9% at Dalby and Moree. The lint yield would increase 2% to 24% in 7 out of 12 cases (the combinations of three plant configurations and four locations) and WUE would increase by up to 15% except at Dalby in a double-skip configuration. Lint yield in rain-fed cotton responded the most (positively or negatively) at double-skip planting at Emerald, Dalby and Narrabri, while it decreased the most at single-skip planting at Moree.

Key words
Climate change, irrigated cotton, rain-fed cotton, water use efficiency, row configurations, modelling

Introduction

The impact of climate change including elevated CO_2 concentration (eCO_2) on cotton production has attracted attention since the 1990s. Both experimental and modelling studies have been conducted to address this important issue. Mauney et al. (1994) found that cotton water use efficiency (WUE) would increase under eCO_2 across irrigation levels and the increase in WUE was due to increased biomass production rather than a reduction of water use. Reddy et al. (2005) investigated the interactive effects of eCO_2 and temperature on cotton production and found that doubling of CO_2 concentration did not ameliorate the adverse effect of high temperature on reproductive growth (boll abscission or boll size). Reddy et al. (2002) quantified the effects of future climate change on cotton production in the Mississippi Delta by using the cotton simulation model GOSSYM with the effects of eCO_2 considered. A recent study by Luo et al. (2014) quantified the impact of increase in temperature on cotton crop phenology and the occurrence of cold shocks and heat stress for the period centred on 2030 in Australia. Changes in the probability of cold shocks and heat stress occurrence and in cotton phenology arising from future climate change will affect cotton growth. For example, an increase in temperature will increase water loss due to soil and plant evaporation, and increase the frequency of exceeding critical temperature thresholds for crop growth and development (Reddy et al., 2005), hence impact on cotton growth, boll production, fibre quality, and ultimately farm profitability. Even though eCO_2 may have some positive effects on cotton production, these effects may be constrained or impacted by high temperature, and access to soil water and soil nutrients (Reddy et al., 2005). For the Australian cotton industry to be sustainable, there is a strategic need to quantify the combined impacts of changes in temperature, rainfall, and eCO_2 on cotton production. This will help to identify and evaluate existing and potential adaptation options in the face of climate change. This research aims to quantify the potential impacts of future climate change on cotton production from the perspective of cotton lint yield, water use and WUE.

Methods

Study locations

For irrigated cotton, we considered nine major cotton production areas in Queensland (Emerald, Dalby, St George, and Goondiwindi) and New South Wales (Moree, Bourke, Narrabri, Warren and Hillston). The irrigated cotton production areas represent different growing environments, with Emerald, Bourke and St George being classified as hot; Dalby, Goondiwindi, Moree, Narrabri and Warren as mild; and Hillston as cool. These environments have resulted in varying crop management practices such as different sowing dates. For rain-fed cotton we focused on four rain-fed cotton production areas, namely Emerald, Dalby, Moree and Narrabri.

Local climate change & climate change scenarios (CCSs)

Dynamic downscaling is one of the major downscaling approaches for translating coarser spatial resolution climate change information to finer scales (Luo & Yu, 2012). In this study, the outputs of the CSIRO Conformal Cubic Atmospheric Model (CCAM), a dynamic downscaling approach, for baseline (1980-1999) and future period (2020-2039), were used by a stochastic weather generator, LARS-WG, to derive monthly local climate change information and to construct long time series (100 yrs) of climate scenarios. The CCAM model was driven by four general circulation models (GCMs), specifically, GFDL, CSIRO Mark 3.5, MPI, MIROC under the Special Report on Emission Scenarios (SRES) A2 greenhouse gas emission scenario (IPCC, 2000). Detailed procedures for constructing local CCSs and justifications for the downscaling approach, study periods, emission scenarios, and the number of climate models considered can be found in Luo et al. (2014, 2015).

The OZCOT model

CSIRO OZCOT model (Hearn, 1994) was used in this study to quantify the effects of future climate change on cotton lint yield, water use and WUE. The OZCOT model is a mechanistic model, which simulates the growth, development and lint yield on an area basis at a daily time step. This model was developed for Australian cotton production systems and has been validated for both irrigated and rain-fed cotton across a range of environments (Richards et al., 2008). This model has been modified to capture the physiological effects of eCO_2 on cotton production. Details can be found in Luo et al. (2015).

Simulation design

In this simulation analysis, cotton cultivar: S71BR was used. This cultivar is a high yielding modern cultivar with mid to late maturity, mimics high fruit retention associated with transgenic cultivars conferring high levels of insect pest protection. Table 1 shows the common sowing time for each cotton production area under current climate (Bange et al., 2010). Irrigated cotton was simulated on a 1 m row solid planting configuration as per industry standard practice. A water supply level of 8 ML/ha for each location was considered. Table 2 summarises the irrigation management rules used. Skip-row is commonly used to ensure viable cotton crop yield and fibre quality in rain-fed systems. A simulation analysis across three planting configurations (i.e. solid, single skip, and double skip) was carried out to assess climate change effects on cotton production across the four locations. The soil profile characteristics used by the OZCOT were selected as being representative of the major soil types for each location. Of particular importance in these simulations is the plant available water capacity of the soils, which is shown in Table 1. Nitrogen was assumed to be non-limiting to exclude its interaction with climate change and was set to an initial value of 200 kg/ha at sowing. An additional 50 kg/ha of fertiliser N was applied at approximately first flower for each location. The timing and amount of fertiliser N applied are in line with current cotton management practices. Atmospheric CO_2 concentration for baseline and future period were set to 400 ppm and 450 ppm respectively.

Table 1. Sowing time and plant available water capacity (PAWC in mm/mm) across locations

Locations	Sowing Time	PAWC
Emerald	25th Sep	220 mm
Dalby	15th Oct	250 mm
St George	1st Oct	170 mm
Goondiwindi	25th Sep	245 mm
Moree	25th Sep	180 mm
Bourke	1st Oct	110 mm
Narrabri	10th Oct	260 mm
Warren	1st Oct	210 mm
Hillston	25th Sep	140 mm

Table 2. Irrigation management information

Irrigation schedules	Value
Pre-irrigation time (days)	12 days before sowing
Deficit irrigation trigger (mm)	70 mm
Timing of 1st irrigation (days)	2 days after 1st square
Timing of last irrigation (%)	20% of open bolls

Results

Local climate change in 2030

Table 3 shows the multimodel ensemble mean changes between future period (2020-2039) and baseline period (1980-1999) in growing season (1st Oct – 31st May) mean rainfall, minimum and maximum temperature and the variability of mean temperature. From this table it can be seen that mean rainfall would increase by 2% to 16% across locations with southern areas increasing more. Minimum temperature would increase 1.1°C to 1.3°C and maximum temperature would increase 0.9°C to 1.1°C across locations. Mean temperature variability (defined as standard deviation) would increase by 5% to 9% across locations except for Emerald where a 2% decrease was found.

Table 3. Multi-model ensemble mean changes of climatic variables over cotton growing season for the period centred on 2030

Locations	GSR[1] (Ratio change)	Tmin[2] (°C)	Tmax[2] (°C)	Tvar[3] (Ratio change)
Emerald	1.02	1.23	1.07	0.98
Dalby	1.06	1.27	1.13	1.05
ST George	1.08	1.29	0.99	1.06
Goondiwindi	1.09	1.30	1.08	1.06
Moree	1.09	1.27	1.05	1.07
Bourke	1.11	1.21	1.05	1.09
Narrabri	1.10	1.26	1.04	1.07
Warren	1.14	1.22	0.96	1.07
Hillston	1.16	1.14	0.94	1.06

[1] growing season mean rainfall; [2] minimum/maximum temperature; [3] mean temperature variability

Simulated cotton lint yield, water use and WUE under irrigated condition

Table 4 shows the multi-model ensemble mean changes in cotton lint yield, water use, and WUE across the nine production areas under climate change conditions in 2030 with water supply level of 8ML/ha. It was found that cotton lint yield would change from -8.2% to +0.5% in 2030 across locations with Hillston decreasing the most. A change range of -3.0% to +2.7% would be expected for cotton water-use with seven out of nine locations showing a decrease. Cotton WUE would change from -11.0% to +2.1% with seven out of nine locations showing a decrease.

Table 4. Multi-model ensemble mean changes (%) in cotton lint yield, water use and WUE in 2030

Locations	Lint Yield	Water Use	WUE
Emerald	-1.68	-0.10	0.75
Dalby	0.53	1.91	-1.93
St George	-4.64	-1.84	-2.87
Goondwindi	-1.60	-3.35	2.07
Moree	-2.46	-2.70	-2.71
Bourke	-7.65	-2.94	-7.29
Narrabri	-1.82	-0.64	-1.70
Warren	-2.67	-2.82	-3.37
Hillston	-8.23	2.74	-11.03

Simulated cotton lint yield, water use and WUE under rain-fed condition

Figure 1 shows multi-model ensemble mean changes of cotton lint yield, water-use and WUE across planting configurations and study locations for the period centered on 2030. Cotton lint yield would increase 7% to 24% at Emerald and Narrabri across planting configurations and would decrease by 14% at Dalby and Moree (except for single skip at this location) under future climate scenarios (Figure 1a). Planting configurations: solid

and double-skip would result in greater increases in lint yield when compared to single-skip configuration at Emerald and Narrabri. However, single-skip performed the best at Dalby and Moree in a changing climate. From Figure 1b it can be seen that cotton water-use would increase 3% to 6% at Narrabri and Emerald except for solid configuration at this location, while it would decrease from 5% to 9% at Dalby and Moree across planting configurations in a changing climate. Future climate scenarios would have positive effects on cotton WUE by 15% across locations and planting configurations except at Dalby associated with double-skip (Figure 1c).

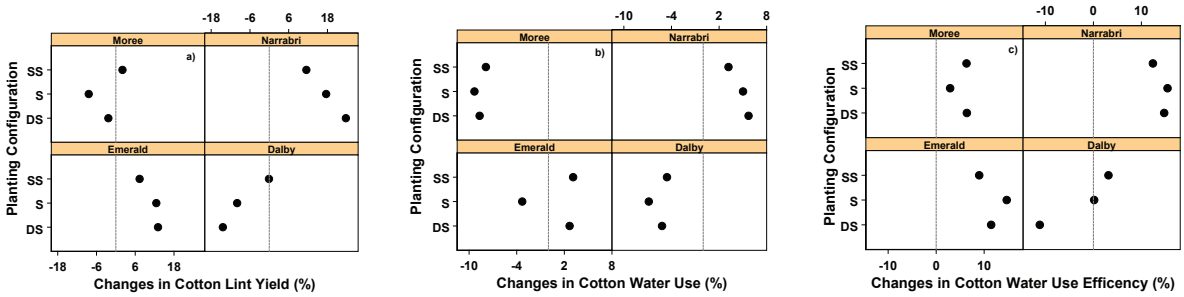

Figure 1. Multi-model ensemble mean changes (%) in cotton lint yield, water use and WUE in 2030 under rain-fed condition. SS: single skip, S: solid, DS: double skip. The dotted vertical lines represent no change.

Discussion and Conclusions

Cotton lint yield, water use and WUE would decrease at most of the locations considered under climate change and irrigated conditions (Table 4). Decrease in cotton lint yield may arise from exacerbated waterlogging problems under a high water supply level (8 ML/ha) and projected increase in cotton growing season rainfall (Table 3). The greatest decrease in cotton lint yield data at Hillston is probably due to the greatest increase in growing season rainfall (Table 3) under irrigated condition. The greatest decrease in cotton lint yield coupled with an increase in cotton water use (Table 4) led to the greatest decrease in WUE at this location. The physiological effects of eCO_2 may have offset the negative effects of future climate change thus led to small decline in cotton lint yield at other locations. On the other hand, increased season rainfall would benefit cotton lint yield under rain-fed condition. For rain-fed cotton, double skip planting would respond positively to future climate scenarios at Emerald and Narrabri while single skip planting would perform the best in terms of lint yield at Dalby and Moree. This indicates that adaptation options in dealing with climate change issues are site- and farming system-specific. These findings have practical value to the Australian cotton growers. The effectiveness of adaptation strategies such as changing planting time, irrigation schedule and rotation pattern on cotton lint yield has been evaluated in a couple of studies by Luo et al. (unpublished).

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Simulation modelling of alternative strategies for climate change adaptation in rainfed cropping systems in North-Western Cambodia

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Abstract
Cambodia experiences a tropical monsoon climate with the wet season from May to October and the dry season from November to April. The average annual temperature ranges between 25 and 30 °C but has been increasing by 0.18 °C per decade since 1960. Cambodia's average annual rainfall of around 1,400 mm has not changed significantly since 1960 and is not expected to change significantly into the future, but projections indicate a trend for less rainfall early in the wet season and a later finish to the wet season. The objective of this study was to examine impacts and adaptation options to existing and potential climate variability and change among smallholder farms in the rainfed upland regions of North-West (NW) Cambodia. In recent years, these farmers plant crops on isolated rain events in the dry season from February onwards and their crops often fail because of drought and high temperatures at crop flowering. The main wet season crop is generally planted in July-August and crops can be lost from damage by heavy rain at harvest. APSIM was used to explore options to reduce crop climate risk by varying sowing date, applying alternative crop sequences and crop residue management. The potential climatic and agro-ecological constraints to adoption of safer and more profitable cropping strategies in the rainfed upland of North-West Cambodia are discussed.

Key words
Cropping; climate change; impacts; adaptation; APSIM

Introduction

There is a growing concern about the impact of climate variability and change on agricultural production across the world (Kotir, 2011). Increasing temperatures and changing rainfall patterns may contribute to increased frequency of extreme climatic events worldwide, thereby increasing production risk and crop yield losses. The severity of impact is likely to vary for individuals, systems and regions (Smith et al., 2001). Developing countries are more vulnerable to adverse impacts from increased climate variability and change because they are more reliant on agriculture for their livelihoods (Kotir, 2011).

Cambodia experiences a tropical monsoon climate with the wet season from May to October and the dry season from November to April. Rainfall generally begins in February and ends in November, with the highest rainfall months being September and October. The average annual temperature for Cambodia ranges between 25 to 30°C, but has been increasing by 0.18°C per decade since 1960 (McSweeney et al., 2012). The target region for this study is North-West (NW) Cambodia centred on the city of Battambang (13°05' N, 103°13' E, elevation 39 m). Battambang's average annual rainfall of 1,327 mm has not changed significantly since 1960. However, records show a trend towards less rainfall early in the wet season and a later finish to the wet season. Local farmers perceive rising temperatures, changing precipitation patterns and delayed commencement of the wet season (Touch et al., 2014). In NW Cambodia, farmers plant crops on isolated rain events in the dry season from February onwards. Crops often fail because of drought combined with high temperature at flowering which results in poor seed set, especially in maize. The main wet season crop is generally planted in August and crops can be lost from damage by heavy rain at harvest. Farmers reported they experienced crop failures, yield losses and associated income losses and they assumed climate was the main cause of the problems (Touch et al., 2014). On-farm research in NW Cambodia has shown that the main factors affecting maize yield are drought stress, declining soil fertility and weed competition (R. Martin pers. comm.). Research has also shown that reduced tillage and preservation of crop residues on the soil surface can conserve soil moisture and result in reduced risk of crop failure and increased yields (Montgomery

pers. comm.). Therefore, this study aimed to improve understanding of how climate variability affects crop production on smallholder farms in NW Cambodia and to explore options to reduce climate risk. This was achieved by using the Agricultural Production Systems Simulator (APSIM) (Keating et al. 2003) to explore the impacts of varying sowing date, crop sequence and crop residue management under current and projected future climate scenarios.

Methods

Descriptions of field and simulation experiments

To calibrate APSIM, data were used from field experiments conducted between 2009 and 2013 at two locations with contrasting rainfall: Samlout (>2,000 mm p.a.) and Pailin (approximately 1,200 mm p.a.). Seven field experiments were carried out between 2009 and 2013 (ACIAR 2015) at including Samlout and Pailin. All experiments were conducted on a Ferrosol – which has a red, clayey surface soil with a friable structure and clay subsoil. The experiments were laid out in a randomised complete block design with three replicates. The experiments included early and main wet season maize nutrient experiments in 2009, examining the grain yield responses of different rates of urea applications: 0, 50, 100, 150, 200, 250, 400 and 450 kg/ha (5 experiments in Samlout and Pailin). Additionally, a sunflower plant population experiment conducted in the main, wet and dry seasons of 2012 – 2013 (both in Samlout and Pailin) tested different plant populations (i.e. 1.5, 1.9, 2.3, 3.0, 3.9, 5.2 and 6.7 plant/m^2).

The soil characteristics of a ferrosol soil from Kingaroy Australia (APSOIL #65) which closely matched the study sites were used in the simulation. The soil parameters were adjusted using soil data from the regional and experimental sites, thereby reasonably representing the soil characteristics. The default cultivar parameters of maize (cultivar Pioneer 3527) and sunflower (cultivar SunGold) in APSIM 7.7 were used. The simulation designs for sowing times, plant populations and fertilizer applications were in accordance with the field experiments. Rainfall data used for the simulation validations were from the Pailin weather station (12°52’ N, 102°36’ E, elevation 170 m) and the Maddox Jolie-Pitt Foundation field headquarters at Samlout (12°40’ N, 102°45’ E, elevation 180 m).

Simulation experiments

Two simulation experiments were run using climate data from Veal Bek Chan Meteorology Station at Battambang (13°05’ N, 103°13’ E), approximately 80 km from the study sites. Future climate projections for Battambang were derived from the BCC-CSM1.1 GCM (BC1) Global Circulation Model (GCM) under Representative Concentration Pathway Scenario 8.5 (RCP8.5) of the fifth phase of the Coupled Model Intercomparison Project (CMIP5). The BC1-RCP8.5 showed high capacity to simulate regional climate for the study site and the GCM downscaling processes and techniques were detailed in Liu and Zuo (2012). Plant densities per square metre were 7 for maize and 4 for sunflower.

Simulation 1 was designed to examine yield responses from various sowing months under current climate and future climate projection conditions. The current climate observations were collected at Veal Bek Chan Meteorology Station between 1982 and 2013. The projected future climate was grouped into two time frames; 2014-2057 and 2058-2100. Soil fertility was reset at each sowing time to avoid the confounding effects of declining soil fertility. This allowed the model to generate yield responses to climate and soil residual water only.

Simulation 2 was designed to investigate yield responses from a maize-sunflower crop sequence. Maize was planted on June 1, followed by sunflower sown on October 1, with various amounts of crop residues (i.e. 0, 1, 2 and 3 t/ha) being retained in the field. These two sowing dates were selected based on the outputs from Simulation 1. Soil fertility and soil water were not reset at each sowing in this simulation.

Results

Evaluation of model performance

The simulated crop yields were compared with the observed yields of the maize nutrient (a) and sunflower plant population (b) experiments. The determinant coefficient (R^2) and root mean squared error (RMSE) were utilised to qualify the model performance. The results showed that the simulations had strong correlations with the observations, with reasonably low values of RMSEs (Figure 2). This suggested APSIM could simulate maize and sunflower yields in NW Cambodia with reasonable accuracy.

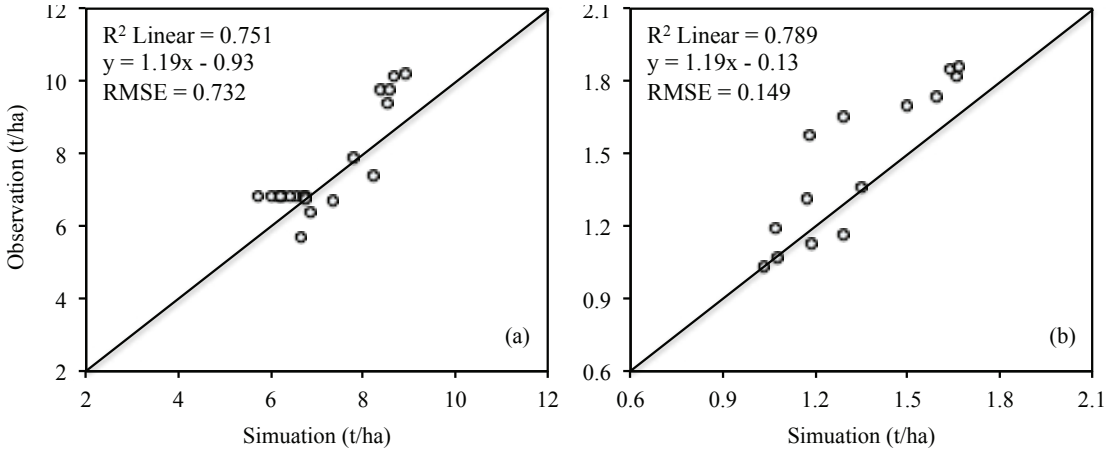

Figure 2. Observed and simulated yields of maize *(a)* and sunflower *(b)*. Perfect agreement between simulated and observed values is indicated by the 1:1 line.

Effects of sowing time on maize and sunflower yields

Preferred sowing dates for maize and sunflower under the projected future climate were similar to the best sowing dates under current climate (in August), and between June and September (Figure 3). Planting crops in February and March was risky in the current climate and even riskier with the future climate projection. The results showed there was a 25% chance of crop failure under current climate conditions (Figure 3a) and 50% chance of crop failure under the future climate projection (Figure 3b, 3c) for February sowing. The results suggested that farmers should consider adjusting their sowing dates to reduce the risk of crop failure in current as well as future climate scenarios (Figure 3).

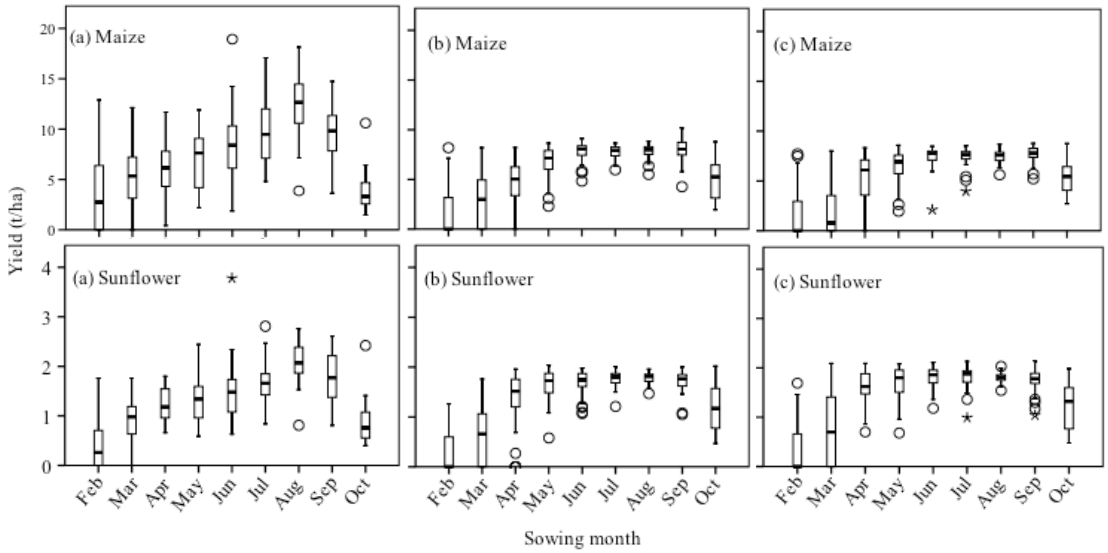

Figure 3. Effects of varying sowing months on simulated maize and sunflower yields planted on the first day of each month using observed current climate 1982-2013 and projected future climate between over 2014-2100. (a) refers to period: 1982-2013, *(b):* 2014-2057, and *(c)*: 2058-2100.

Maize-sunflower rotation as an option to adapt to projected future climate

Planting maize in June appeared to reduce drought impacts on crop growth. June planting also has reduced risk of wet weather damage during ripening and harvesting, compared with other crops such as soybean and mungbean. Sunflower planted in October was more likely to receive rain during the first 4-6 weeks of crop growth, but thereafter relied on residual soil water to grow to maturity. The results showed there was a significant maize yield response between 0 and 1-3 t/ha of crop residue retention at p-values ≤ 0.01 under current climate (1982-2013) and p-values < 0.001 under climate projection (2014-2100), but there was no significant difference between 1, 2 and 3 t/ha (Figure 4).

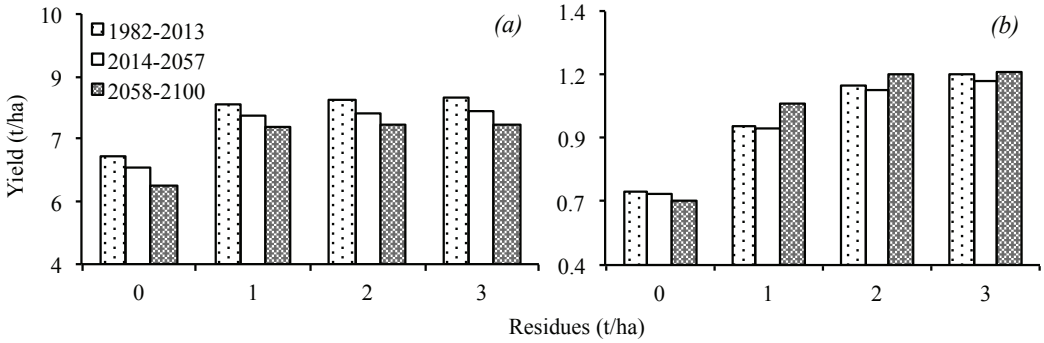

Figure 4. Comparing yields of maize (a) planted in June and sunflower (b) planted in October with varying levels of crop residue retention (0, 1, 2 and 3 t/ha) under current (1982-2013) and projected future climate scenarios (2014-2100).

Sunflower under current climate conditions, did not show a significant yield response (p-value = 0.061) when retaining residues of 1 t/ha. Significant differences (p-values ≤ 0.009) can be seen for retained residues of 2-3 t/ha. Under the future climate projection there was a significant difference (p-values < 0.001) between 0 and 1-3 t/ha of the residue retention; but not between 1, 2 and 3 t/ha.

Discussion and conclusions

We found that crops planted in February and March appear to be at risk of drought-induced crop loss under current climate conditions, and at even higher risk under potential future climate projections. This is consistent with observations by local farmers that there are major adverse effects from climate on their crop production (Touch et al., 2014). This risk, based on potential future climate projections, can be reduced by sowing the first crop in May and the second crop in September.

One alternative cropping strategy that is less risky than the current cropping practice is to sow maize in June followed by dry season sunflower planting in October, along with retained crop residues. Preserving crop residues has positive effects on crop yield, especially for the dry season crop. Under current climate conditions, maize yield was increased by 1.38 t/ha by retaining 3 tonnes per hectare of crop residues, while sunflower yield almost doubled. This study also highlights that crop models are useful tools to identify potential options for future climates which can then be verified in field-based experiments.

Acknowledgements

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Impact of projected climates on drought occurrence in the Australian wheatbelt

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Abstract
Wheat is a staple crop, and in Australia it is primarily produced in rainfed environments. Climate change projections indicate an increase in future rainfall variability and in temperature across the Australian wheatbelt. Coupled with the continued increase in demand for this crop due to rising populations and living standards, climate change may significantly impact the Australian wheat industry. The lead times involved in adapting cultivars and management practices mean that planning for adaptation must often begin many years before implementation. Thus timely, realistic assessments of the crop-level implications of climate change are critical to the long-term planning of breeders, farmers and policy makers. Such assessments require extensive analysis of the complex interplay between local environment, genotype, and adaptive management practices. In this study we capture these interactions for 60 representative sites using the APSIM-Wheat crop model, and simulated the impact that 33 climate model projections had on the distribution of drought environment types across the Australian wheatbelt. Simulation results indicate that changes in future drought patterns are highly region-specific. Significant variations in projected changes were found across climate models, giving local ranges of uncertainty to consider in planning efforts. However, simulations for the majority of climate models projected increased frequencies of severe drought conditions in the Western area of the wheatbelt, and fewer severe droughts in other regions. Overall, simulations indicate that all areas of the Australian wheatbelt will continue to experience drought conditions this century, and that adaptation planning is necessary to match future wheat demand.

Key words
wheat, climate change, water deficit, environment characterisation, crop modelling, APSIM

Introduction

Due to the combination of increasing population and rising living standards, demand for staple foods such as wheat continues to increase. Most Australian wheat is produced in water-limited environments, and is exported. Recent climate projections indicate that Australia will experience increased temperature and rainfall variability this century (Zheng et al. 2012; Reisinger et al. 2014), which may have substantial implications for the local wheat industry. As it takes 5-15 years to produce new cultivars, timely assessments of the plausible impacts of climate change are of vital importance (Chapman et al. 2012).

Both the degree and timing of environmental stressors influence crop development (e.g. Fischer 2011). Thus, assessing the impact of abiotic stressors on wheat requires careful consideration of the complex interactions between the local environment, crop genotype, and management practices (Chenu 2015). In this study, we used the APSIM-Wheat model (Holzworth et al. 2014) to capture these interactions at 60 representative sites across the Australian wheatbelt. Seasonal patterns in the water-stress index output by the model were classified to identify key seasonal patterns of water-stress, termed 'drought environment types' (Chenu et al. 2013). For each site, a set of future climate scenarios were generated using the projections of 33 climate models from the Coupled Model Intercomparison Phase 5 Project (CMIP5; Taylor et al. 2012). The wheat model was run for each site's current and future climate scenarios, and every simulated season was classified into one of four drought environment types. The main aims were to (1) assess likely changes in occurrence of drought across the wheatbelt, and (2) identify the range of potential changes projected by this large ensemble of climate models.

Materials and Methods

Characterizing current drought environment types

Crop simulations were performed using the Agricultural Production Systems Simulator (APSIM Version 7.6) for the wheat variety 'Hartog' (*Triticum aestivium* L.). For each of the 60 representative sites, two sets of

simulations were performed using historical weather observations from 1955 to 2013, obtained from SILO (Jeffrey et al. 2001). The first set was performed to identify five representative sowing dates and five initial soil water levels for each site, according to local conditions and management practices (see Chenu et al. 2013 for details). These sowing dates and initial soil water values were selected to each represent 20% of the sowing opportunities and soil water conditions, respectively. The resulting 5x5 initial conditions for each site were used in the second set of simulations, to characterize the drought patterns experienced by current wheat crops across the wheatbelt.

For each model run, a daily water-stress index was computed to reflect crop 'water supply/demand ratio', i.e. the ratio of potential soil water available to the crop to the amount that the crop could use for potential transpiration. This index ranged from 0 (no water available to the crop) to 1 (no water stress). Water-stress patterns for each environment (i.e. each unique site, year, sowing date and initial soil water combination) were defined as the water-stress indices averaged every 100°Cd, from 100°Cd after emergence to 450°Cd after flowering.

The 'clara' clustering function (Maechler et al. 2015) was used to group these water-stress patterns into four sets to define four drought 'environment types' (ET; see Figure 1).

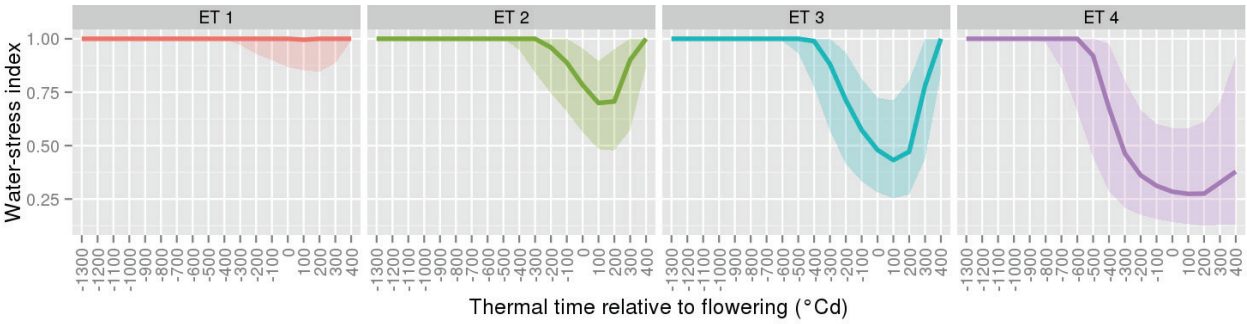

Figure 1. Water-stress patterns defining the four main environment types (ET) identified for the Australian wheatbelt. For each environment type, the median (coloured line) and variations from the 10th to the 90th percentile of the distribution (shading) are presented.

Projecting future environment types

The monthly output of 33 climate models from CMIP5 (Taylor et al. 2012) were used to generate the set of future scenarios by downscaling daily observations from SILO. We employed data from the Representative Concentration Pathway (RCP) 8.5 scenario, which assumes 'business as usual' CO_2 emissions. For each site, future climate scenarios were generated according to each climate model for three distinct time periods centred on 2030, 2050 and 2070 (baseline: 1955 to 2013). All 99 future scenarios were the result of transforming the local daily historical temperature and precipitation values by their projected future local monthly means. For each climate scenario, the water-stress patterns of each site, year, sowing date, and initial soil water combination were simulated as described above (with one set of simulations to identify initial conditions specific to each climate model, and one set of simulations to characterize drought patterns).

In total, 9.2 million crop simulations were performed (1 historical scenario + 99 future climate scenarios) x ((60 sites x 59 years) + (60 sites x 59 years x 5 planting dates x 5 initial soil water values)), which required the equivalent of over 100 days of computing time on a current processor (2.93GHz Intel Xeon X5570). In real time, these simulations were completed in approximately 2.5 days on the University of Queensland's high performance computing facility. Results were stored as compressed NetCDF files using the Python netCDF4 package[1], and the differences between future scenarios and the baseline for the frequency of occurrence of different ETs were processed and analysed using R[2].

Results and Discussion

Future projections for drought patterns varied significantly across climate models, even by 2030, primarily due to differences in projected precipitation. This is consistent with recent work showing that these climate

1 https://github.com/Unidata/netcdf4-python
2 http://www.R-project.org/

models broadly agree on future temperatures, but do not agree on future precipitation patterns in Australia (Reisinger et al. 2014).

Two key aspects of these results are (1) the range of projected environment type responses, and (2) consensus that can be found among the climate models, which indicate likely future impacts.
To assess the range of impacts, climate models were ranked according to their projected changes in occurrence of severe drought environments (ET 3 and 4; Figure 1). Figure 2 presents the range of projected changes in ET occurrence for the most optimistic (CESM1-BGC), the central (MRI-CGCM3), and the most pessimistic (GFDL-ESM2M) climate models.

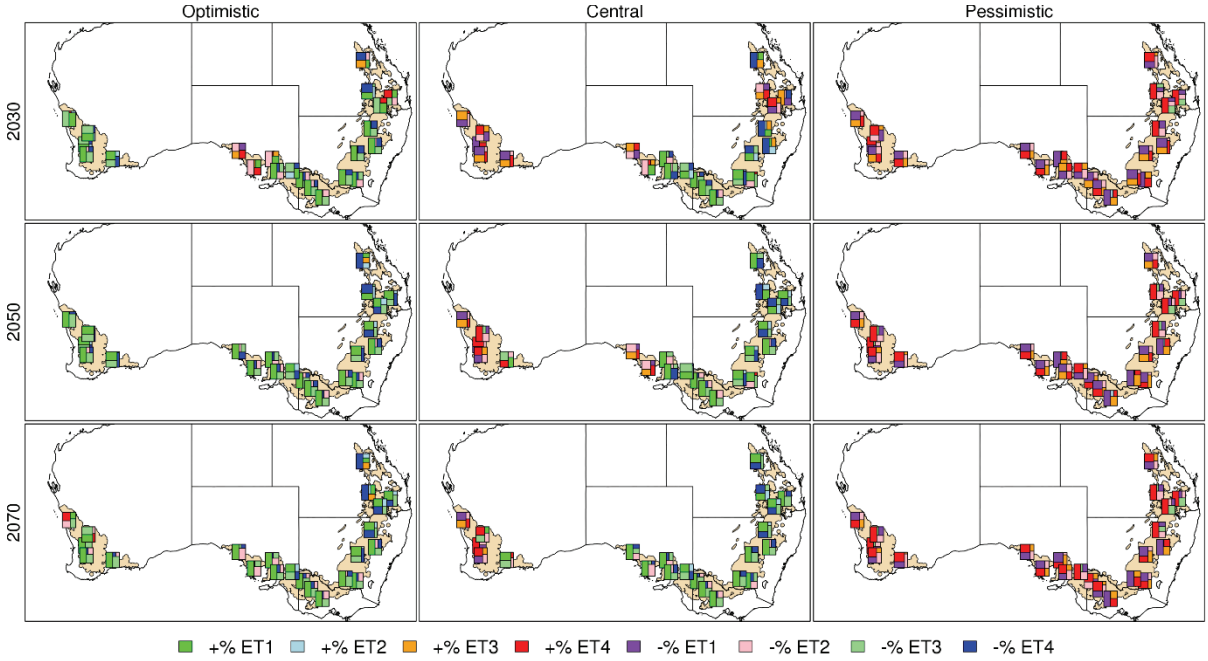

Figure 2. Regional averages for projected changes in the frequency of occurrence of environment types across the wheatbelt for three future periods (rows) and three contrasting climate models (columns). The coloured proportion of each box indicates the change in occurrence of each environment type compared to the baseline (1955 to 2013). Projections are presented for 2030, 2050 and 2070 and optimistic, central, and pessimistic climate models (see text).

Clear variations among climate models were found, even by 2030. While increased frequencies of severe drought conditions in the West of the wheatbelt were projected by both the central and pessimistic climate models, the optimistic climate model projected a decrease in these conditions. In contrast, in the East and South-East of the wheatbelt, the optimistic and central climate models indicated a decrease in severe drought conditions later this century. This reduction was primarily driven by shorter crop cycles arising from higher temperatures, and increased transpiration efficiency due to raised CO_2 concentrations. Note that the primary differences in the future drought predictions presented in Figure 2 derive more from the climate model considered than from the projection time.

When assessing the projections of all 33 climate models, occurrences of severe drought environments (ET 3 and 4) were found to decrease this century in the East, South and South-East of the wheatbelt (Figure 3). In contrast, the majority of climate models projected that the Western area of the wheatbelt will experience significant increases in drought conditions.

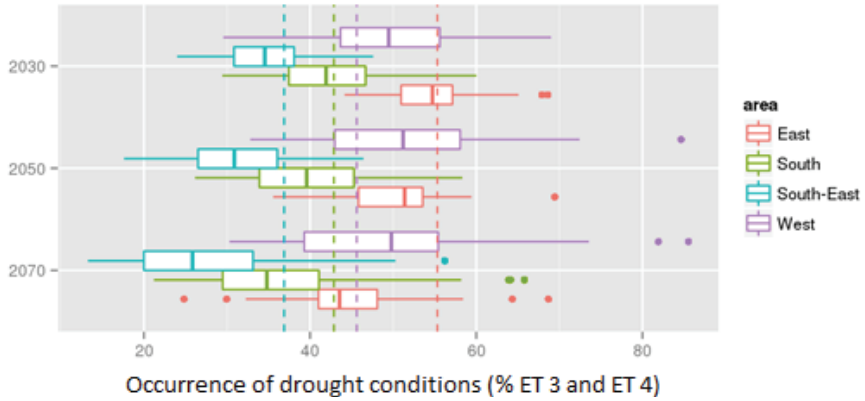

Figure 3. Projected occurrence of drought environments (ET 3 and 4) per major wheat-producing area, compared to historical occurrence (dotted lines). Boxplots summarize the distribution of percentages for each of the 33 climate models.

Conclusions

Climate model projections indicate that the West of the Australian wheatbelt is likely to experience increased drought conditions as early as 2030. Given the lead times involved for crop adaptation, and the western wheatbelt's significant contribution towards total national production, these results provide a strong case for immediate initiation of adaptation planning for this area. Other areas of the wheatbelt are projected to experience decreased frequencies of drought conditions, with rising temperatures shortening the crop cycle and CO_2 concentrations allowing more efficient water use. However, even where the frequencies of severe drought conditions are projected to decrease, their occurrences are projected to remain substantial. Overall, increased demand for wheat means that Australia must continue to improve cultivars and management practises to mitigate the drought conditions experienced across its wheatbelt.

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Evaluation of a climate model consensus forecast for Victorian farmers, seven years on

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Abstract
For seven years DEDJTR have been producing a newsletter called the Fast Break that summarises climate forecasts for Victoria, effectively bringing two hours of web searching onto an A4 page. The newsletter has a distribution list of 2500 people, 62% of whom are farmers with 37% agribusiness and government advisors. Forecasts from seven Coupled Global Circulation Models (CGCM), two ensembles of CGCM's, and two statistical models were collated in July of each year for predictions of the spring period August-October since June 2008. The eleven model predictions were analysed for agreement and the most common prediction was compared against the actual values. This consensus methods ability to predict NINO 3.4 was excellent, but predictions for Indian Ocean, rainfall and temperature were mixed, but had useful skill in the direction in which to "jump", if not "how far". Consensus of models was almost certainly better than picking one model with most skill and following it. Individual model accuracy was erratic and in some years could lead to perverse outcomes if only one was followed. Best overall model performance for rainfall prediction was for the 2010 La Nina event.

Key words
Newsletter, coupled, global, circulation, ensemble, survey

Introduction
Increases in modern computing power have meant that statistical seasonal forecasts have been augmented or replaced with Coupled Global Circulation Models (CGCM). Such models have the power to predict climate phenomena based on the laws of physics, without using historical patterns like the statistical systems do. Rather than facing the confusion of which model to choose in which year and at what time, it is possible that there is greater strength in looking at an ensemble of models. Such an ensemble could be better at removing the noise from individual models and seek a consensus prediction. Ensemble predictions have been used for Indian monsoon rainfall out to five days (Kumar *et.al.* 2012), climate predictions for the Asian monsoon (Krishnamurti *et.al. 2006) and the International Research Institute seasonal climate forecasts for the world (Barnston et. al.* 2010). These authors and others have found greater statistical skill in the Multi Model Ensemble (MME) approach, compared to individual models. A cheaper approach (called a poor man's ensemble PME) is used by some meteorological and climatological agencies, where the outputs from other agency models are combined rather than running many expensive models yourself. The Australian BoM uses such an approach in its Water and the Land eight day rainfall prediction using the approach of Ebert (2001). In 2007 the Australian Bureau of Meteorology created a summary of CGCM predictions of temperature in the NINO 3.4 section of the Pacific Ocean. We thought that by looking at a simple MME the eastern Indian Ocean surface temperature, rainfall and land temperature predictions could also be assessed and be of use to Victoria's Agriculture sector. Following seven years of use, we assessed how this consensus forecast performed for spring. Commonly verification studies involve correlation gridded data sets between forecast and observed values. This study has been low-tech, and forecast and observed values have been visually compared.

Methods
In the last week of every month the outputs of the selected models were obtained off the web. Models were chosen according to their ease of web based access and /or English translation. Predictions were obtained from seven CGCM's (System 4 ECMWF 2015 , POAMA2 BoM1 2015, SINTEX-F JAMSTEC 2015, DFSv2 NCEP 2015, Glosea5 UKMO 2015, GEOS-5 NASA 2015 and CGMCM1.0 BCC 2015), two ensembles of CGCM's (IRI 2015, APCC 2015) and two statistical models (Qld SOI phase system DSITIA 2015, WA ESS AEGIC 2015). The outputs for the sea surface temperature (SST) in the NINO3.4 region and Eastern Indian Ocean, rainfall and land temperature were collated into a table and published in the Fast

Break e-newsletter. Thresholds used for El Niño and La Niña and Indian Ocean Dipole positive and negative were > +/- 1.0 oC. If temperatures in both oceanic regions were > +/ - 1.0 oC they were classified as "warm"/"cool", when between +/- 0.5-1.0 oC they were classified as "slightly cooler"/"slightly warmer". When between +/- 0.5 oC they were classified as "neutral". For rainfall, forecast values between +/- 0.1 oC were classified as "average", between +/- 0.1-0.6 mm a day anomaly were classified as "slightly wetter"/"slightly drier", > +/- 0.6 mm/day were classified as "wetter"/"drier". For temperatures values between +/- 0.3 oC were classified as "average", anomalies between +/- 0.3-1.0 oC were classified "slightly warmer"/"slightly cooler", values > +/- 1.0 oC were classified as "warmer"/"cooler". The majority consensus of all eleven model predictions was distilled into one prediction. No weighting was used. Where models were split between two outcomes, we gave both predictions split by "/". Where there was no model consensus we used the prediction of "mixed".

For this study, we looked at the July predictions for spring (August-October) and compared these to the archived actual values for SST from the OSPO NOAA site (NOAA 2015), and the Bureau of Meteorology historic rainfall and temperature maps (BoM2 2015). A qualitative verdict was given for the correctness of the forecasts, taking into consideration the extent of predicted versus actual across the ocean or state of Victoria. When the actual results for the state were varied predictions were split with a "/". When rating forecasts for SST anomalies, a rating of "excellent" was chosen where the model consensus was the same as the actual outcome, "Good" was chosen if the direction of the temperature signal was correct, "Poor" was used if the actual outcome was not in the direction of that predicted. For rainfall and temperature a rating of "Excellent" was given if greater than 66% of the state's area anomalies were similar to that predicted. "Good" was chosen if 33%-66% of the state had an outcome predicted. "Poor" was chosen if less than 33% of the state was represented by the prediction. Not all models present outputs for all parameters we tested, Table 1 shows the various models and the parameters viewable.

Table 1. Models and the parameters available for use in this study.

	Model	Organisation	Country	NINO 3.4	Eastern Indian Ocean	Rainfall	Temp.
CGCM's	System 4	ECMWF	UK	yes	yes	yes	yes
	POAMA2	BoM	Australia	yes	yes	yes	yes
	SINTEX	JAMSTEC	Japan	yes	yes	yes	yes
	CFSv2	NCEP	USA	yes	yes	yes	yes
	GEOS-5	NASA	USA	yes	yes	yes	yes
	CGMCM1.0	BCC	China			yes	yes
	UKMO	GloSea5	UK	yes	yes	yes	yes
Ensembles	IRI	USA		yes	yes	yes	yes
	APCC	Korea		yes	yes	yes	yes
Statistical	SOI phase	DSITIA Qld	Australia			yes	
	ESS	AEGIC WA	Australia	yes		yes	

Results

Data are presented for the seven years of August to October predictions and their actual outcomes. The consensus of 11 models was excellent at predicting NINO3.4 sea surface temperatures, with the exception of 2012 where a weak El Niño was predicted to form but failed to materialise in spring (Table 2).

Table 2. Predicted and actual outcomes for August-October NINO3.4 temperatures, and a qualitative assessment of correctness.

	Predicted	Actual	Assessment
2008	neutral	neutral	excellent
2009	El Niño	El Niño	excellent
2010	La Niña	La Niña	excellent
2011	slightly cool	slightly cool	excellent
2012	Weak El Niño	neutral	poor
2013	neutral	neutral	excellent
2014	slightly warm	slightly warm	excellent

Consensus of models had fair performance at predicting eastern Indian Ocean sea surface temperatures correctly predicting three out of seven years (Table 3). Furthermore, predictions were partly correct during 2010 and 2011. In 2012 an IOD+ (Indian Ocean Dipole) occurred with little notice that was only predicted by the ECMWF model. In 2013 all models, bar the IRI ensemble predicted an IOD- which failed to occur.

Table 3. Predicted and actual outcomes for August-October eastern Indian Ocean temperatures, and a qualitative assessment of correctness.

	Predicted	Actual	Assessment
2008	IOD+	IOD+	excellent
2009	neutral	neutral	excellent
2010	slightly warm	weak IOD-	good
2011	neutral/weak IOD+	weak IOD+	good
2012	Mixed	IOD+	poor
2013	IOD-	neutral	poor
2014	slightly warm	slightly warm	excellent

Consensus of models generally had good success at predicting spring rainfall, although only half of the models generally made the correct prediction (Table 4). The exception was the wet La Niña year of 2010 where at least the trend of the rainfall response was in the right direction.

Table 4. Predicted and actual outcomes for August-October rainfall, and a qualitative assessment of correctness.

	Predicted	Actual	Assessment
2008	average/slightly drier	drier	good
2009	slightly drier/average	average/slightly drier	good
2010	slightly wetter	wetter	excellent
2011	average	slightly drier/average	good
2012	average/slightly drier	drier	good
2013	average	mixed	good
2014	Average/slightly drier	drier	good

Consensus of models had mixed performance at predicting spring temperatures (Table 5). Actual temperatures were dominated by slightly warmer springs, with the exception of the cooler 2010 La Niña which tripped many models up, with the exception of POAMA. In 2013 only IRI and NASA successfully predicted the warmer spring.

Table 5. Predicted and actual outcomes for August-October temperatures, and a qualitative assessment of correctness.

	Predicted	Actual	Assessment
2008	slightly warmer/average	slightly warmer/average	excellent
2009	slightly warmer	average/slightly warmer	good
2010	Slightly warmer	average/slightly cooler	poor
2011	average/slightly warmer	Slightly warmer	good
2012	average/slightly warmer	Average/slightly warmer	excellent
2013	mixed	slightly warmer/warmer	poor
2014	slightly warmer/average	warmer	good

Discussion

Due to the year to year erratic nature of individual model performance (data not presented), the use of multi-model ensemble forecasts provides some greater clarity, but is still less than the perfection that farmers desire, but may never obtain. Greatest skill was in the prediction of NINO3.4 temperatures. Predictions for the eastern Indian Ocean, Victorian rainfall and temperature were not as good but exhibited useful skill at getting the signal direction right on many occasions. The rainfall predictions are the most agricultural important as nitrogen fertiliser decisions can be made through August and September in many medium to high rainfall districts. Interestingly, there were no poor predictions made by the consensus system where the actual outcome was opposite to that predicted. Such perverse outcomes would cause decision makers to lose the most money from an unpredicted event. Using the results of just one model would occasionally lead to perverse outcomes where the prediction was radically different to the consensus. Rainfall predictions often

contained a signal to the actual outcome but were rarely perfect. At some times a mixed signal could be considered useless, but often implies that individual model variability is so great, that decisions should be made on more known parameters, such as rainfall to date and stored soil moisture. The August to October period is the time where models should have the greatest skill, so it could be implied that predictions made outside this period might have poorer skill than was seen here.

Conclusion

CGCM consensus forecasting had good skill for the prediction of NINO3.4 temperature in spring but mixed skill in other parameters. Improved climate literacy of the how and when of using seasonal forecasting is critical if farmers and advisors are to apply these tools in their on farm decisions. While climate modelling and computer power is improving forecast skill, it will be important to deliver development and extension programs such as The Break to ensure knowledge, trust and utilisation of forecasts by farmers improves.

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Different response of soil and crop sequences to climate change in Western Australian mixed farm systems

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Abstract
Western Australia is a major producer and exporter of crops and much of the production comes from mixed crop-livestock farms. Climate drives the productivity and profitability of these farms. Therefore, the effects of likely climate change on farm performance need to be understood. Here, the effects of climate change at 2030 were evaluated compared to a baseline period (1980-1999) on mixed farming systems for different soil types and rotation systems using the coupled APSIM and GRAZPLAN biophysical simulation models. Different crops' yields under historical and projected climates were assessed using current technology and management practices, including interactions with livestock. Representative mixed-farm systems were selected along a climate transect. Compared to the baseline, in 2030 crop yields had different responses to changes in climate in soil x current rotations, except for lupins. Under the hotter and drier potential climate of 2030, the greatest positive effect on wheat and barley yield was 20% (Katanning, Shallow sandy duplex, rotation: AAAWC) and 37% (Cunderdin, Deep loamy duplex, rotation: WPWCB), while there was no increase projected for canola and lupin. The greatest decline of wheat and barley yield was 20% (Mullewa, Coloured sands, rotation: WLWC) and 16% (Cunderdin, Shallow sandy duplex, rotation: AAWCB, Katanning, Grey sandy duplex, rotation: AAB). Overall, current long term average productivity of rotation systems × soil type may change in near future depending on degree of changes in climate, suggesting requirement for optimizing current rotation systems to obtain maximised production and profitability.

Key words
Climate change impact, modelling, agricultural system, cropping

Introduction
Climate change predictions suggest that the scale and rate of change driven by increases in concentration of greenhouse gases in the atmosphere is unprecedented in human history, and will significantly – and in many cases dramatically – alter the accessibility and quality of natural resources (IPCC, 2014). Changes in key climatic variables such as temperature, rainfall, and atmospheric CO_2 will act to push agro-ecosystems towards their thresholds of change, which potentially can threaten the future of agricultural industries and communities dependent on them. In this paper we explore the impact of changing climate on the agricultural productivity of mixed farming enterprises in Western Australia (WA). Western Australia is a major contributor to the Australian agrifood sector and economy with mixed farming enterprises practiced over diverse climates and soil types. In the 2012/13 financial year the Western Australian cropping industries exported a total of $3.9 billion with $2.2 billion of wheat exports (8.5 million tonne) (Department of Agriculture and Food, 2013). A wide range of soils occurs in south-western Australia. These soils, including those at the representative sites, are of varying depth with the majority having sandy topsoils with low clay content and organic matter and are often constrained by acidity (Anderson and Garlinge, 2000; Moore, 2001). Agriculture in WA is possible because of the relatively reliable winter rainfall under the region's Mediterranean climate. This region has temporal variability of rainfall and evidence of an overall decline in winter rainfall over the past century. The effects of climate change at 2030 were evaluated compared to a baseline period (1980-1999) on mixed farming systems for different soil types and rotation systems using the coupled cropping and animal enterprises. This work presents modelling of the complex interactions among climate, soil, crops, pasture, and animal within a whole farm system. This modelling of the potential impact of climate change is a first step toward designing adaptation strategies.

Methods
We selected four representative mixed farming systems across a climate gradient of 241-369 mm growing season rainfall (Apr-Oct) using the base period 1980-1999. These sites range from the dryer inner edge of the grains belt to the medium-high rainfall zone and represent complex agro-ecosystems with different

soils, farm and livestock management, input intensity and scale of operation. Facilitated workshops were used to select the sites and characteristics of representative farms. Stakeholders at the workshops included farmers, representative of farmer groups, consultants, and research and extension officers of Department of Agriculture and Food Western Australia. At these workshops we agreed on soil type, landuse, pasture, cropping and livestock. This was complemented by available literature along with published and unpublished surveys (Co-operative Bulk Handling, 2013 unpublished; ABARES, 2014).

Coupled Model Intercomparison Project Phase 5 (CMIP5) models were used for likely future climate of "Hot and dry", "Hot and moderate changes in rainfall", and "Warm with least changes in rainfall" (Table 1). Two "representative concentration pathways" RCP 4.5 and RCP 8.5 scenarios (IPCC, 2013) were applied with high and low sensitivity that allowed us to sample across the more likely range of possible future climates in the focus year of 2030 using three global climate models (GCM): HADGEM2-AO, GFDL CM3, and MIROC5. These GCMs were statistically downscaled using the quantile matching method which produces daily weather data sequences. Combinations of RCP 8.5 x high sensitivity x GFDL CM3 considered as hot and dry (HD), CP 8.5 x high sensitivity x MIROC5 GCM, hot and increased rainfall (HMCR), and CP 4.5 x low sensitivity x HADGEM2-AO, considered as potential climate of warm with modest changes in rainfall (WLCR) (Table 1). Atmospheric CO_2 concentrations of 435 ppm for 2030 under the RCP 4.5 and 449 ppm under RCP 8.5 scenarios were assumed. For the baseline, monthly atmospheric CO_2 concentration measured in Cape Grim station was used for period of 1980-1999 which ranged between 335.7 ppm and 366.5 ppm.

Each representative site had several soil types and rotation systems (Table 2). A representative range of soils for each site was characterized using APSoil database. Most soils had topsoils that are relatively low in clay and soil organic matter and were frequently constrained by acidity. Consequently, the fertility and water holding capacity is low. The main crops of wheat, barley, canola, lupin, and field pea were simulated. Field peas were used in the model as a green manure. Pasture species identified are annual ryegrass, subterranean clover, and biserrula. The baseline sowing date window and reference wheat cultivar for each site were selected based on local conditions via producer workshops and the Planfarm Bankwest Benchmarks (Anonymous, 2014). Sowing for all crops was simulated when 5-day (Cunderdin and Katanning) or 3-day (Mullewa & Merredin) total rainfall exceeded 10 mm. The only reset in the modelling was for biomass and humus at the end of rotation. Soil organic matter (SOM) of pastures was reset at the first day of year. To evaluate the effect of rotations there was no resetting of soil water or N. Biophysical simulation models of integrated crop-livestock systems were constructed by linking the APSIM soil water, soil nutrient cycling, crop and surface residue simulation models to the GRAZPLAN pasture and ruminant simulation models (Donnelly et al., 2002) using the AusFarm modelling software (version 1.4.7). Here, additional functions were applied to account for frost and heat stress on crops further to APSIM's current formulation. Management systems were described using flexible rules that allocated land to the different crop-pasture sequences and then managed the sowing and removal of the various crop and forage species, nitrogen fertilizer (N) applications, the annual cycle of sheep reproduction, buy and sale, supplementary feeding and grazing management. Simulated crop yields were validated through producer workshops and with regional database of Co-operative Bulk Handling (CBH) (Anonymous, 2014 unpublished) for a period 1996-2013 as the best proxy yield data available.

Results

In the hotter and drier HD future temperature was projected to increase between 1.0 °C and 1.4 °C across the transect with smallest and greatest increase at Katanning and Mullewa, respectively. Under the warm with modest change in rainfall WLCR future the temperature increase across sites was between 0.5 °C and 0.7 °C. Annual rainfall declined in all sites and all future climates but there were differences in seasonality. There was an increase in spring and late-summer (February) rainfall projected at most sites, however, it was accompanied with increased temperature.

When compared to the 1990 baseline (that is the period from 1980-1999), projected crop yields in 2030 declined for most of the combinations of crop × site × future climates, with less decline in the WLCR future than the HD future (Table 2, Fig 1). The changes in crop yields differed according to crop, rotation by soil combination and future climate. Crop yields of lupin declined in all instances and canola yields in all but one instance. The declines were by up to 27% for lupin in the HD future and 19% in the WLCR future, and by up to 24% for canola in the HD future and 18% in the WLCR future. Wheat yields declined more often than

not (12 out of 17 situations in both the HD and WLCR futures) with most of declines being more than 5%. The declines in wheat yield were up to -16% in the HD future and -11% in the WLCR future (both Mullewa), but the increases were up to 12% and 20% for HD and WLCR, respectively. Barley yields in future climates were almost equally likely to increase as they were to decrease. When barley yields were simulated to increase, the barley typically followed a canola crop in the rotation sequence.

Table 1. Projected future climates

Likely future climate	Abbreviation	Scenario	Sensitivity	GCM
Hot and dry	HD	RCP 8.5	High	GFDL CM3
Hot and moderate changes in rainfall	HMCR	RCP 8.5	High	MIROC5
Warm with least changes in rainfall	WLCR	RCP 4.5	Low	HADGEM2-AO

Table 2. Relative change (%) in crop yields in 2030 of each crop x soil type x rotation for HD and WLCR potential future climates compared to the baseline. A: annual pasture, W: wheat, C: canola, B: barley.

		HD				WMCR			
Katanning	Soil	Wheat	Barley	Canola	Lupin	Wheat	Barley	Canola	Lupin
AAAWC	Shallow sandy duplex	-14%		-7%		20%		-1%	
AAB	Grey sandy duplex		-16%				-2%		
AAWCB	Shallow sandy duplex	0%	18%	-4%		-8%	3%	-1%	
ACWB	Deep loamy duplex	12%	0%	-5%		0%	0%	-4%	
AWCB	Deep loamy duplex	-1%	21%	-2%		-1%	1%	2%	
Cunderdin									
AAACW	Gravelly sand	-7%		-16%		-5%		-15%	
ABWLW	Acide yellow sand	1%	-2%		-15%	-1%	0%		-14%
WLWCB	Deep sandy duplex	1%	9%	-18%	-15%	-1%	6%	-15%	-13%
WPWCB	Deep loamy duplex	-7%	37%	-20%		-7%	35%	-18%	
Merredin									
AAW	Yellow deep sand	-13%				-6%			
WBWBB	Shallow loamy duplex	-2%	0%			-3%	12%		
WWCWWL	Yellow brown sand	-3%		-14%	-22%	5%		-8%	-11%
WWCWWP	Yellow brown sand	-7%		-15%		-1%		-10%	
WWWC	Gravelly duplex	-5%		-24%		3%		-12%	
WWWCB	Yellow brown sand	5%	-3%	-12%		8%	-2%	-6%	
Mullewa									
WCWB	Coloured sands	-16%	-11%	-22%		-7%	-12%	-15%	
WLWC	Coloured sands	-20%		-20%	-27%	-11%		-14%	-19%
WWWB	Red shallow loam	-12%	-16%			-8%	-9%		

Modelling results indicated a 12% increase in wheat yield at Katanning (HD). The current management includes wheat grazing in AAAWC, and AAWCB rotations on low quality shallow sandy duplex soils which resulted in simulations of late flowering and low yields. Wheat yield is very sensitive to the timing of flowering, a common rule of thumb is a 5% reduction in yield for every week that flowering is delayed. This reduction will be exacerbated with added damage functions for heat waves. A major impact of a hotter climate will be earlier flowering. The low water holding capacity of these soils rather than insufficient nitrogen fertilizer were simulated to be the causal factor in low yields as indicated by up to 266% higher whole year soil water stress of photosynthesis (total daily water uptake by roots/soil water demand of plant) in shallow sandy duplex soil compared to the other soils. Nitrogen stress for photosynthesis was not significantly different among rotation and soils. The future climates altered the amounts of water stress. For example, at Katanning, soil water stress for wheat changed differently among soils and rotations under different scenarios of climate change. The rate of change of long term average soil water stress of wheat in the ACWB rotation compared to the historic baseline increased by up to 87% under HD future and by up to and 25% in the WLCR future. However, for wheat in the AWCB rotation (deep loamy duplex) soil water stress decreased by -31% and -38% under HD and WLCR futures respectively.

Conclusion

There was generally a negative effect of changes in climate on crop yields across soils and current rotation systems while some positive effects were also realized. Water and nitrogen stresses varied among soil × crops × rotation systems × potential climate in comparison to the historical climate. Long term average productivity of rotation systems × soil type may change in near future depending on degree of changes in climate, suggesting requirement for optimizing sequencing systems to obtain maximised production and profitability.

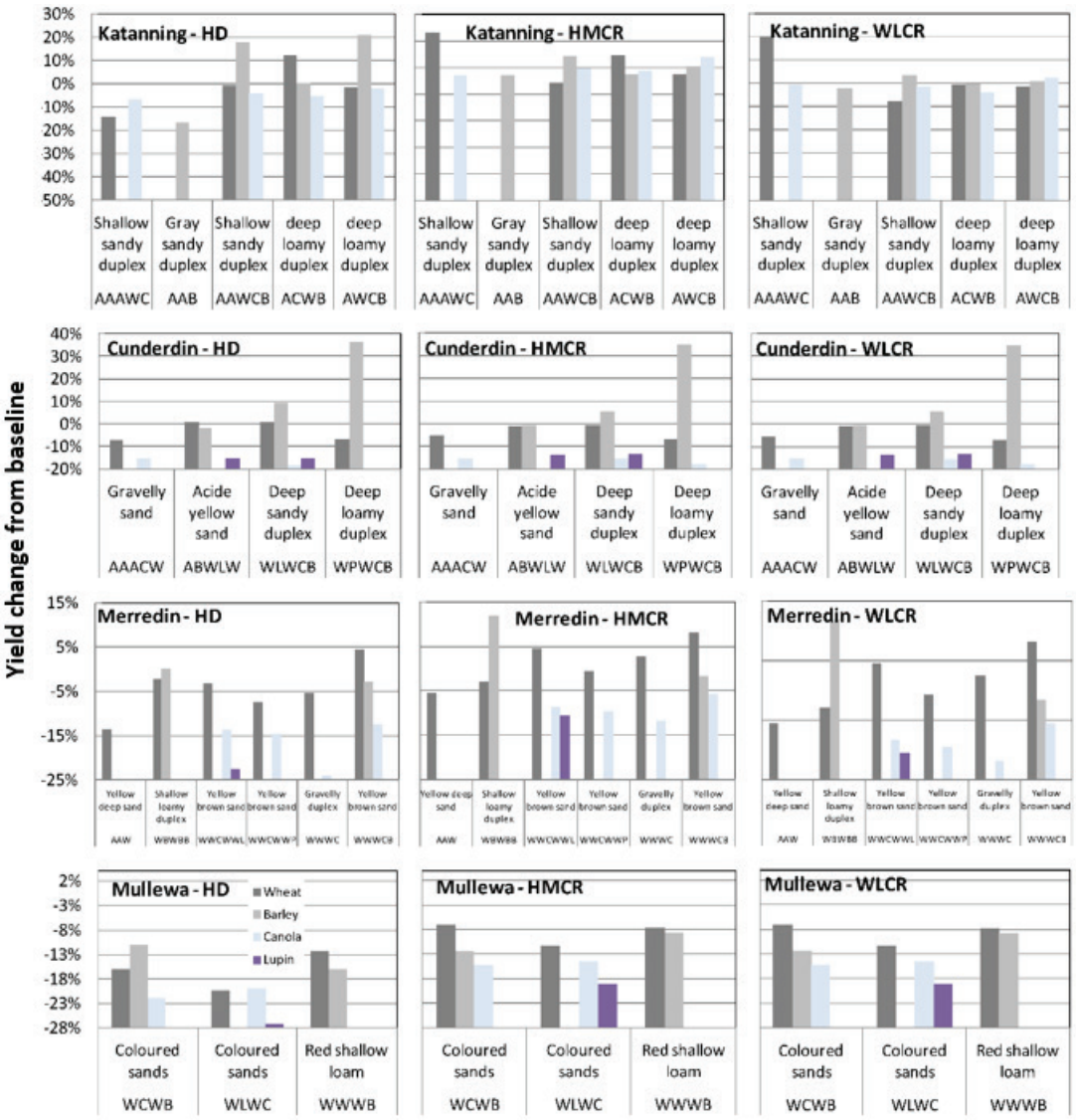

Figure 1. Relative change in crop yields under potential climates compared to the baseline.

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Is mosaic irrigation a viable proposition for north Australian beef enterprises?

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Abstract
Few north Australia beef enterprises generate positive returns in most years or achieve the necessary productivity gains (~2% per annum) to offset an ongoing cost-price squeeze. Lack of high quality forages is a major factor inhibiting herd productivity and, notwithstanding a long history of R&D, the uptake of improved pastures, including irrigated pastures and forage crops, remains limited. Despite longstanding interest, outside a few large scale developments (e.g. Ord River, Douglas-Daly, Mitchell and lower Burdekin), there has been little development of irrigation in the north and especially for integrating sown forages into extensive beef production systems. There is scope for sufficient irrigation water to exploit 60,000-120,000 ha of suitable soils, a 200-400% increase of the present irrigated area. 'Mosaic' irrigation, small scale dispersed developments based on suitable soils and extraction sites, appears to offer a technically attractive option for exploiting the available ground water resources; and especially by individual northern beef enterprises. However, it is largely untested and indications of the scope for economic benefits are scarce. Simulation models using regional case studies (Kimberley, Barkly Tableland, and Charters Towers) are employed to explore the scope for mosaic irrigation to change the production and marketing orientation of representative beef enterprises and deliver economic benefits. The results are contrasted with two commonly employed alternative development options for seeking productivity gains (e.g. broad-scale pasture sowing, water and fencing infrastructure).

Key words
Beef cattle, pasture development, economics, simulation

Introduction

The north Australian grazing lands span a vast (2.3 million km2) and diverse array of soil and vegetation types, primarily used for beef production from native pastures under extensive low-input grazing systems. The region carries over half the national herd (~14 million head), but despite major structural and technical transformations (e.g. breeds, infrastructure, transport, market orientation), few enterprises generate profits in most years or achieve the necessary productivity gains (~2% per annum) to offset the cost-price squeeze (McCosker *et al*. 2010). A significant contributor to poor business performance is the low reproductive performance of breeders, management of first calving heifers, calf growth rates and liveweight gain (McCosker et al. 2010). This can be linked to nutrition management and the low quality of native pastures (especially in the annual dry season) which is a legacy of the restrictive climatic and edaphic context. Despite the availability of mature pasture improvement technologies (Gramshaw and Walker 1988), and with the notable exception of some significant regional cases (e.g. Brigalow *Acacia harpophylla* and Gidgee *Acacia cambagei* communities), most enterprises have no areas of developed pasture or cropping land (Bortolussi *et al*. 2005). Where it has occurred, pasture development is mainly confined to savanna vegetation communities in Queensland based on mechanical tree clearing with sown pastures (grass species or mixes of grasses and legumes) or tree poisoning to exploit of elevated native herbage yields.

While interest in tapping the runoff from high annual seasonal rainfall, extensive areas of land and proximity to Asian markets for irrigation development is longstanding, outside a few large scale developments (e.g. Ord River, Douglas-Daly basin, Mitchell catchment and lower Burdekin River), few irrigation activities have developed across northern Australia1, especially for integrating forage cropping or higher productivity pastures into extensive beef production systems. Critically, expansion of irrigation is actually limited by water resources, especially in the peak demand dry season, with sufficient available water to only exploit 60,000-120,000 ha, or less than 1%, of a total area of ~49 million ha deemed technically suitable for

[1] The area of land under irrigation in the majority of statistical regions in northern Australia is less than 1% (MacLeod *et al.* 2013).

cropping or forestry[2] (Webster et al. 2009). Moreover, exploitation of surface water resources is likely to be highly contested with conservation and cultural alternatives. 'Mosaic' irrigation, small-scale dispersed developments based on suitable soils and extraction sites equipped with bores, has been suggested as a technically attractive option for exploiting the available ground water resources; and especially by individual beef enterprises to increase their productivity and capital efficiency by improving the amount, quality and timeliness of feed supplies (Webster et al. 2009). Beyond some hydrological advantages of reduced salinity, runoff and erosion from dispersed cf. concentrated large-scale developments, the small-scale and lesser capital requirements may lead to some operating and capital cost efficiencies that have eluded larger schemes with high costs for infrastructure, delivery and regulation. It may also be amenable to adaptive management by relatively unskilled or inexperienced newcomers to irrigation design and management thereby promoting its accelerated adoption (MacLeod et al. 2013).

However, mosaic irrigation practice on beef holdings has been largely untested under either research or farm practice and indications of the scope for economic benefits are scarce. As part of a formal review conducted by CSIRO for the Office of Northern Australia, we employed crop and beef herd production simulation models and regional case studies to explore the scope for mosaic irrigation to change the production and marketing orientation of representative northern beef enterprises and deliver economic benefits (MacLeod et al. 2013). The results of three of the case studies are summarised in this paper. Brief consideration is also given to the returns for three alternative development options that have been promoted in northern Australia viz. broad-scale pasture sowing, cell grazing, and water and fencing infrastructure.

Simulation Modelling Approach

Irrigated forage utilisation scenarios were developed for a representative beef enterprise located in each of five regional sites based on agro-ecological contexts and the orientation of markets for sale stock (MacLeod et al. 2013).The yield of irrigated forages grown on a standard soil (Grey Vertosol) at a site within the five regions (Burdekin in Queensland, Barkly Tableland and Victoria River District in the Northern Territory, and Pilbara and Kimberley in Western Australia) was simulated with APSIM (Keating et al. 2003) for three broad categories of forages - forage sorghum (annual forage grass), lablab (tropical legume) and bambatsi panic (tropical perennial grass) - at two times of year (spring and autumn) for direct grazing or producing hay. Irrigation scenarios and costings were based on a pivot irrigation development utilising a local bore and diesel pump for a scale sufficient to meet irrigation demands in 80% and 100% of years (Petty 2011). The NABSA beef herd economic simulation model (McDonald 2012) was calibrated for a representative beef enterprise in each region to generate estimates of animal productivity (growth, reproduction, mortality), turnoff and net profitability (gross margin, net economic profit, and return on investment) for the suite of simulations. The simulation runs for economic modelling were for 20 years (1990-2010). Sensitivity testing was undertaken on the simulated profit projections for each irrigation development scenario by varying several parameters (e.g. livestock price, irrigation cost, total costs).

Case study examples – Barkly Tableland, Burdekin, Kimberley

Within the restrictions of this paper, it is not feasible to comprehensively describe and present the results of all of the irrigation development scenarios for each crop type, sowing time, enterprise type and region, and parameter sensitivity test employed in the study - this information is available in the formal project report (MacLeod et al. 2013). Here we briefly describe a single scenario encompassing the most productive forage type and season of planting with 80% irrigation reliability for three of the regional case studies and summarise the results (without sensitivity tests). The budgets that were employed used livestock prices and production input costs that were applicable in each regions at the time the study was conducted (late 2013).

Barkly Tableland (NT) - 5,000km2 holding, carrying a 22,000 head Brahman breeding herd turning off 24 month old steers for live export to Asia via Darwin at ~350kg liveweight/steer. The average stocking rate is ~5.6 adult equivalents (AE)/km2. Irrigation scenario is 550ha (development cost = $5,000/ha) of irrigated lablab fed to the steers in late spring/summer to reach a minimum liveweight of 580 kg/steer by 42 months.

[2] This would still represent a two to fourfold increase of the existing irrigated cropping area (Webster *et al.* 2009).

Burdekin (Qld) - 30,000ha holding, carrying a 1,800 head Brahman breeding herd turning off heavy steers for slaughter in Townsville at a minimum liveweight of 580 kg/steer at ~42 months. The average stocking rate is ~1 AE/8 ha. Irrigation scenario is 50ha (development cost = $7,300/ha) of irrigated bambatsi fed year around to steers when sufficient standing forage is available to meet the same target weight at 30 months.

Kimberley (WA) - 2,800km2 holding, carrying a 11,000 head Brahman breeding herd turning off 2 year old steers at ~330-350 kg/steer for live export to Asia through Wyndham, although this target is infrequently met (24% of years) due to seasonal conditions with an average turnoff weight of ~276 kg/steer. The average stocking rate is ~4 AE/km2. Irrigation scenario is 60ha (development cost = $7,300/ha) of irrigated bambatsi fed year around to the steers when sufficient standing forage is available in late spring/summer to reach the target selling weight (330-350 kg liveweight/steer at 24 months) in 80% of years.

Results

The results of the APSIM-NABSA simulations for the three example scenarios are presented in Table 1.

Table 1. APSIM-NABSA model simulation results for three example case studies. Baseline vs irrigation development. Average for the simulation period 1990-2010.

	Barkly Tableland	Burdekin	Kimberley
	Baseline - nil irrigation		
Total stock carried (AE)	26,774	2,867	10,876
Gross Margin/AE	$114	$122	$62
Av. Net profit	$1,643,763	$155,406	$25,867
Av. Turnoff liveweight/steer	303	535	276
	Irrigation development (80% reliability)		
Irrigated crop	Lablab	Bambatsi	Bambatsi
Scale (ha)	550	50	60
Capital investment	$4.7 million	$422,750	$507,300
Irrigation cost - annual operating	$329,505	$32,205	$53,046
Irrigation cost - annualised capital	$448,016	$40,729	$48,874
Total stock carried (AE)	31,502	2,644	11,248
Gross Margin/AE	$137	$182	$81
Av. Net profit	$2,595,958	$257,295	$229,249
Av. Turnoff liveweight (kg/steer)	583	585	349
Av. Return on investment	20%	24%	40%

For the three illustrative development scenarios that are presented here, the availability of irrigated forage does increase the productivity of the modelled enterprise, either by increasing the total number of stock carried[3] and/or increasing the productivity of the sale animals. The projected (mean) return on the mosaic irrigation development investment is also positive, ranging between 20% to 40%. The range across all of the scenarios that were examined in the wider study is between -5% and 40%, with the negative returns largely associated with scenarios based on irrigated forage sorghum which requires much larger areas to achieve the production goals and hence higher development costs (MacLeod et al. 2013). The relative advantage of the annual legume and perennial grass over the cereal largely stems from their being either relatively high quality when they are available for off-take (lablab) or being available for grazing over a longer period each year (bambatsi). Despite being positive, it should be cautioned that returns of this order, especially on an additional investment for an existing enterprise, would likely be classed as borderline investments by some contemporary farm business analysts (Malcolm et al. 2005). However, when the irrigation development was able to secure the opportunity for the targeted stock to reliably meet the target market in most years with a relatively small development scale and the gain per animal is high or shifts to a more valuable sale class, such as applied for the Kimberley bambatsi development, the projected returns (40%) are quite favourable.

Non-irrigation pasture development options

Irrigation is not the only forage-based option available to northern beef enterprises for achieving productivity and economic gains. Other options might include (a) broad-scale development of existing native pastures

[3] The total AEs are actually reduced slightly for the Burdekin case study due to the reduction in age cohorts of the steers.

through either sown pastures (e.g. buffel grass, Rhodes grass) or augmenting existing swards with oversown legume species (e.g. stylos), (b) sub-division of grazing land into smaller parcels to support some form of short duration-higher frequency grazing management systems, or 'cell grazing', or (c) additional investment in property infrastructure to increase the effective grazing area (e.g. stock waters and subdivisional fencing).

These options were also explored in the wider study (MacLeod et al. 2013) for a limited range of regions – drawing on either the NABSA simulations or other published studies. Some estimated returns from these studies are summarised in Table 2. These results are of a similar magnitude to those presented in Table 1 for the mosaic irrigation scenarios. The main point to note here is simply that the operators of northern beef enterprises will have a number of avenues for increasing the productivity of their grazing operations, and some of these options may be competitive with mosaic irrigation options.

Table 2. Projected returns on investments in non-irrigated pasture developments.

	Broadacre pasture development	**Conversion to cell grazing**	**Water & fencing infra-structure**
Region	Burdekin (Qld)	Fitzroy (Qld)	Barkly Tableland (NT)
Av. return on investment	24%	10%	21%
Study reference	Hunt *et al.* (2012)	Hall *et al*. (2011)	MacLeod *et al.* (2013)

Concluding Remarks

The northern beef industry critically needs to increase its productivity to retain the viability of its constituent enterprises in the longer-term. As nutrition is a key driver of herd performance and market opportunity, access to quality feed resources at critical times is an obvious focus for operators. Mosaic irrigation has been signalled as a potential means to meet this goal. Under prevailing climatic and resource endowment and market prices and input costs, the irrigation option appears to show promise in terms of raising herd productivity and meeting some marketing goals. However, a clear picture of the economic advantage of mosaic irrigation is yet to emerge from field experience. The projected returns from the simulation modelling exercise are generally positive, especially for higher quality forages such as cereal legumes and perennial grasses, but not yet unduly competitive with alternative investment options available to enterprises such as broad-acre pasture development, novel grazing systems or further intensification of paddock infrastructure.

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Monitoring impacts from broadscale resource development on surface water flows in agricultural landscapes

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Abstract
Significant landscape change is occurring in the highly productive agricultural regions of Southern Queensland, Australia as a result of coal seam gas (CSG) expansion. Resource development brings with it a high risk of hydrological impact and increased erosion due to extensive addition of roads and infrastructure. Future landscape transformation risks impacting surface hydrology at both the farm and wider catchment. Knowledge of existing overland surface flow is essential in reducing impacts from development of service roads, culverts, well pads, pipeline corridors and water storage reservoirs. Surface flow models derived from fine scale digital elevation models (DEMs) are an appropriate tool for monitoring impact of the wider CSG footprint on surface hydrology and in identifying potential problems during early negotiation and decision planning of future infrastructure. Aerial digital photogrammetry with a ground sample distance of 20 cm was used to create elevation models for a 1200 km^2 focal region currently undergoing CSG development. Baseline digital terrain models were processed using a multi-direction flow-path prediction model. Results demonstrate a capacity to generate high-resolution contoured surfaces and flow-path prediction maps capable of identifying erosion rills and depressions in fields, effectiveness of erosion management structures, and changes in surface water flows caused by farm tracks. These maps have the potential to improve discussions between farmers and the CSG industry and allow for better CSG-farm designs now, and ongoing monitoring of water flow impacts into the future.

Key words
GSG, photogrammetry, digital surface model, water accumulation map

Introduction

Queensland's coal seam gas (CSG) and liquefied natural gas (LNG) industry has over $50 billion of projects either operational or under construction and is currently the driving force of significant landscape change in the Darling Downs and Maranoa agricultural regions of Southern Queensland. Gas reserves of 28613 PJ have been identified on approved tenements covering over 24,000 km^2 (Huth et al., 2014). While regional scale social and economic benefits of CSG development are purported, few studies have evaluated the social and economic impact on farming households that must now coexist in a "shared space" with large-scale resource extraction enterprises (Huth et al., 2014). Large corporations seeking to superimpose a CSG footprint are negotiating directly with landholders on infrastructural changes in the form of access roads, culverts, pipeline corridors, well pads and water storage reservoirs on the existing farming enterprise. These 'ad-hoc' negotiations are generally commercial in confidence and implemented on an individual farm basis. For the more intensively farmed landscape, these changes bring a high risk of hydrological impact and increased erosion due to extensive addition of roads and infrastructure. Market competition abounds between companies in this space and without closer coordination and/or collaboration between all parties, development has the potential to impact stakeholders from farmers (loss or diversion of overland flow from catchment areas, silting of farm dams), local councils (ineffective drainage lines, flooded roads), state government (water quality of streams, river systems) to CSG enterprises (flooding of existing infrastructure). Reducing this risk requires contextual understanding of the topological landscape and surface hydrology at the farm, catchment and regional scale and has the potential to inform discussion between farmers and the CSG industry and allow for better CSG-farm designs now and in the future. This research evaluates the effectiveness of a high-resolution surface water accumulation model for identifying and monitoring changes

to surface water flow or soil elevation that may indicate diversion of water flows, soil loss or build up of sediment, in agricultural landscapes.

Methods

High performance computing based aerial digital photogrammetry was employed in generating image mosaics and in the creation of a digital surface model (DSM) at 20 cm resolution for a 1200 km^2 focal region currently undergoing CSG development on the eastern edge of the Surat basin (26.839 S, 150.333 E). The digital aerial photography is acquired at suitable resolution for fine-scale terrain modelling and was radiometrically calibrated to ground reflectance with methods described in detail by Collings et al. (2011). Radiometric calibration allows generalizable and repeatable image processing techniques to be applied to the data as a whole to derive spatially and temporally consistent information, for example when wanting to classify crop types or remnant vegetation. LiDAR is an alternative technology that may also be employed. From the generated DSM, surface infrastructure and vegetation are then removed by automated methods to generate a ground elevation model (GEM). The GEM was validated against a high-resolution ground survey of 440 surface elevations using a Real Time Kinematic (RTK) GNSS DGPS system. GEMs were then processed using a flow-path prediction model that simulates water flow across a landscape surface (Caccetta et al. 2010). Results of this process are estimates of upslope area and are often referred to as water accumulation maps. These estimates may be colour coded to aid interpretation. In the example in this paper upslope catchment area associated with each 20 cm pixel is colour coded (cyan, green, yellow and red) on a log scale of 0.1 ha to 100 ha with an accumulation area of >100 ha indicated by red. Ground observations of surface water flow paths and erosion rills at 9 locations within the focal region using a DGPS of ±30 cm horizontal accuracy are compared with surface flow paths modelled at 20 cm and 100 cm horizontal resolution.

Results and Discussion

Figure 1a presents an example of a generated image mosaic along with the corresponding colour coded DSM image at 20 cm resolution (Figure 1b) and GEM image with vegetation and above ground structures removed (Figure 1c). While the derived ground elevation model correlated well ($R^2 = 0.94$) with observed elevations, model validation found errors of ~5.0 cm for GEM surface elevations for individual 20 cm pixels when compared with ground measurements approaching the 2.0 cm precision level expected of DGPS systems currently employed in high-resolution site surveys. Flow paths were generated at 20 cm and 1 m resolution with the latter more for display purposes. Figure 1d shows the modelled surface flow paths at 1 m resolution overlaying the image mosaic. Comparison of ground observations at 9 locations (Table 1) confirmed that these high-resolution contoured surfaces and water accumulation maps are capable of identifying erosion rills and depressions in fields, effectiveness of erosion management structures, and changes in surface water flows caused by farm tracks as demonstrated by site number 7 (Figure 2).

While application of satellite acquired remote sensing data for landscape inventory and monitoring is seen as cost effective and has generated reliable information at large spatial scales, their value in fine-scale management has been limited by image resolution (Tuominen and Pekkarinen, 2004). Satellite accuracy and resolution continue to improve, though aerial acquisition still provides a higher resolution which is required for the subtle changes in landscape features considered here. Surface flow models based on a fine scale digital ground elevation model at the catchment scale are an effective tool for monitoring impact of the wider CSG footprint on surface hydrology and in identifying potential problems during early negotiation and decision planning of infrastructure at the farm, shire and regional level. Initial exposure of water accumulation maps in discussions with CSG industry representatives, farm managers and agricultural contractors have confirmed that information on location and catchment area of water flows will help inform landholders and CSG staff during planning for CSG infrastructure placement. Repeated surveys highlight changes in water flow or soil surface elevation and are a cost effective method for managing risk associated with diversion of water flows, soil loss or build up of sediment within the survey area. Sources of any sediment build-up can be easily identified by following the water flow paths to that location.

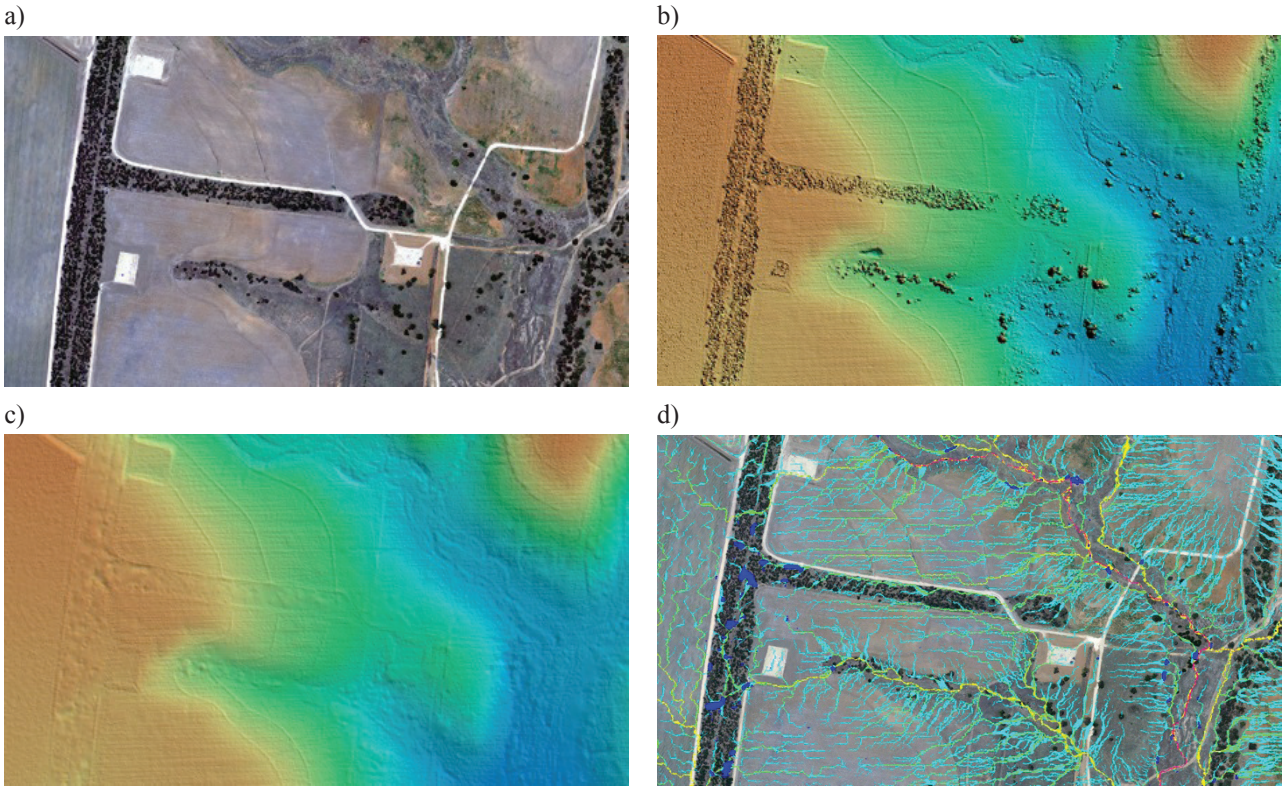

Figure 1. (a) Aerial photogrammetry derived RGB image. (b) Digital surface model (DSM) at 20 cm resolution highlighting treelines and surface infrastructure. (c) Generated ground elevation model (GEM) after removal of above ground structures. (d) Modelled accumulated flow paths indicating low (green) to high (red) accumulation overlaid on RGB image.

Table 1. Location and description of sites used for evaluating modelled flow paths with surface observations.

Site	Latitude (deg)	Longitude (deg)	Sample points	Distance (m)	Description	Agreement	Comments
Grassland and open brigalow and eucalypt woodlands (open canopy)							
1	150.333	-26.811	58	58	Gravel access track	Medium	Minor surface flow crossing track at 2 locations.
2	150.328	-26.819	36	86	Graded farm track (old)	High	Medium surface flows crossing track at 3 locations with flows on track
3	150.329	-26.828	4	9	Gravel access track	High	Medium-high flow. Natural streamline across track.
4	150.329	-26.829	58	123	Gravel access track	High	Medium-high flow crossing track at 2 locations with flows on track. Minor flow crossing track at 2 locations.
5	150.328	-26.832	33	46	Gravel access track	High	Medium-high flow crossing track at 2 locations with flows on track.
6	150.325	-26.834	8	15	Gravel road	Low	Minor flow crossing track.
7	150.322	-26.832	72	195	Gravel road	High	Medium-high flow crossing track at 2 locations with flows along edge of roadway.
Brigalow-eucalypt forest (closed canopy)							
8	150.241	-26.921	104	498	Stream bed	High	High flow major stream path with water holes present. (*dry at time of observation)
9	150.270	-26.910	94	414	Stream bed	High	High flow major stream path with water holes present. (*dry at time of observation)

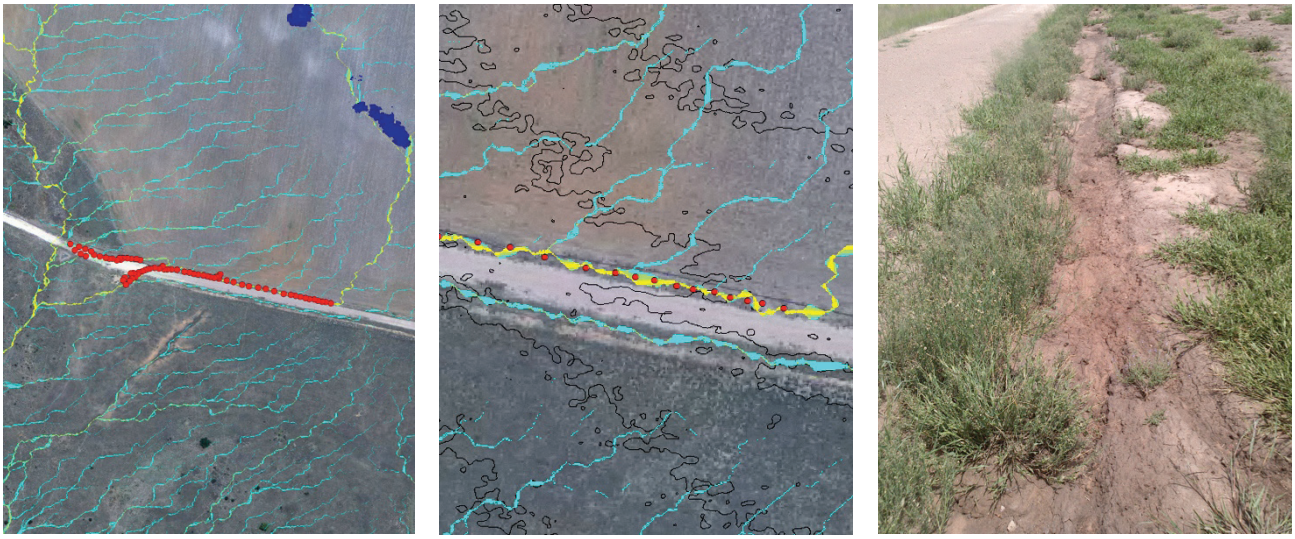

Figure 2. Ground survey site (7) showing (a) survey points overlaid on the aerial image mosaic inclusive of modelled flow paths at 20 cm resolution, (b) subset of 15 survey points overlaid on modelled flow path and (c) observed surface water flow path at figure 2b adjacent the gravelled roadway. Black lines on figure 2b represent contour intervals at 50 cm.

Conclusion

Results demonstrate that use of high performance computing based digital photogrammetry predicts high-resolution surface elevations, enabling generation of landscape scale surface flow maps suitable for assessing impact at the sub-meter level on surface hydrology. Concerns by landholders regarding surface water flows can be better communicated through the use of this technology. These water accumulation or flow maps can inform discussion between farmers and the CSG industry and allow for better CSG-farm designs now and ongoing monitoring of changes in water flow or soil surface elevation which may indicate diversion of water flows, soil loss or build up of sediment, in the future. It is envisaged that acquisition systems and processing will continue to improve in the future and will provide a cost effective method for temporal monitoring of surface hydrology and erosion risk in dynamically changing agricultural landscapes. Future research will focus on extending surface flow modelling to predict and map erosion risk at the farm, catchment and regional scale.

Acknowledgements

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A synthesis of cotton agronomy for productive, diverse and sustainable landscapes

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Abstract
This paper specifically addresses the conference theme "Building a productive, diverse and more sustainable landscapes" using the Australian cotton industry of NSW and Queensland as a case study. A meta-analysis of the Australian cotton agronomy research literature was completed. A report was compiled using the Global Reporting Initiative for Sustainability Reporting Framework using economic, environmental and social indicators. In preparing the report, the Australian Cotton Industry considered more than 100 sustainability indicators and consulted stakeholders to report on 45 aspects of sustainability.

The analysis found that agronomy has increased cotton yield productivity from 1200 to 2270 kg/ha between the 1970s and 2014. Cotton fibre length productivity has increased 97 percent. Water productivity, measured using the Gross Production Water Use Index has improved from 0.79 to 1.14 bales/ML over the last decade. In terms of a diversity, landscape data shows crop rotations with legume and cereal crops have increased. Land use data shows cotton farm diversity in Australia is on average 14% cotton, 29% other crops and 42 % is native vegetation. Research has reported biodiversity on farms such as 153 species of birds and 450 species of invertebrates.

The paper discusses how changes in agronomy practices are building a more sustainable landscape. Data and trends over the last 20 years in land management, water use efficiency, integrated pest management, transgenic crop traits, pesticide use, irrigation practices and farm landscape research will be presented.

Key words
Agriculture, sustainability, cotton, water, environment

Introduction
The conference theme "Building a productive, diverse and more sustainable landscape" raises some questions around what is a sustainable landscape, how is this determined, and how to systematically report diversity. Worldwide demand for food and fibre is increasing to service the needs of a growing population and higher standards of living. Consumers are demanding ethical clarity on their food while communities are striving for more sustainable management of natural resources. Agriculture needs to achieve both the demands for increased output of agricultural products and those for sustainability and ethics. For this to be possible, it is important for farming industries to measure and understand their current sustainability trends and adapt farming practices as required.

The concept of sustainability is a widely used expression, but its actual meaning and understanding tends to be aligned to the user's purpose, emotional intelligence and values. There are a considerable range of views in what constitutes sustainability and the conundrums of the definition. It is more pragmatic to understand how farm industries contribute to ecologically sustainable development and what practices can be modified to further improve their sustainability performance. It is generally accepted that the sustainability concept has three distinct, but related environmental, economic and social components.

Measurement of industry sustainability requires consistent approaches across multiple farms, regions and sites, repeated over long periods of time. Despite considerable industry interest, establishing a core set of indicators and gathering the data is challenging. Performance indicators are needed to monitor production systems and report on their trends towards sustainability. Sustainability indicators will also assist with business planning, resource allocation, and provide documented evidence of natural resource stewardship and community impacts. These indicators will need to have attributes that can be applied at the farm, industry, regional or national level.

There are multiple market driven sustainability initiatives around the globe that expect good data to be available, which is not always easy to achieve. Any ongoing review of selected indicators needs to be balanced by the needs of external stakeholders and challenges of long term data sets. The iterative nature of the process, especially with external stakeholder involvement is time consuming and challenging to do properly.

Sustainability reporting is the practice of measuring, disclosing and being accountable for performance towards the goal of sustainable development and is considered synonymous with other terms used to describe for accounting for economic, environmental and social impacts such as triple bottom line or corporate responsibility (Global Reporting Initiative 2006).The paper applies a sustainability reporting framework to show how changes in cotton agronomy practices are building a more productive, diverse and more sustainable landscapes.

Methods

An inventory of potential sustainability indicators was developed which reviewed the material issues of stakeholders and the literature (Roth 2010). This set of potential sustainability indicators was assessed and updated by the cotton industry's environmental assessment working group, taking into account recent developments in international supply chain sustainability initiatives such as the Better Cotton Initiative, Cotton LEADS™, and the Expert Panel on Social, Environmental and Economic Performance of Cotton Production of the International Cotton Advisory Committee (SEEP 2013).

A list of more than 100 potential sustainability indicators was compiled. These indicators were then prioritised using an objective ranking system which scored indicators against six selection criteria. These criteria included; materiality to cotton industry stakeholders, materiality to external stakeholders, cost effectiveness of data collection, technical difficulty of data collection, data integrity and confidence, and accuracy in the data collection.

From a list of more than 100 indicators, 45 were shortlisted as high priority material aspects for the cotton industry to collect, collate and report as shown in Table 1. A meta-analysis of data was then compiled from a range of sources including the agronomy scientific literature. Some examples are presented as results and a full report according to the Global Reporting Initiative Framework is available (Cotton Australia 2014).

Table 1. Material sustainability aspects and indicators for the Australian Cotton Industry

Key aspect	**Environmental Indicator**
Soil health	1.Organic carbon % 2.Practice change. % growers adopting soil health best management practises 3.Soil sodicity (ESP)
On farm water use efficiency and productivity	4.Gross Production Water Use Index 5.Irrigation Water Use Index 6.Practice change 7. Whole farm Water Use efficiency (%)
Groundwater	8.Groundwater levels (rising or falling) 9.Groundwater quality (EC, pH, SAR)
Biodiversity / riparian	10. Area of native vegetation managed under best practice (ha/km) 11. Vegetation condition and connectivity
IPM	12. % growers using Integrated Pest Management practices
Chemical use	13. Herbicide Use (active ingredient kg/ha) 14. Insecticide use (active ingredient kg/ha)
GHG emissions	15. Energy use (kj/kg cotton lint or bale) 16. Nitrogen Use Efficiency (N use/yield)
Key aspect	**Economic Indicator**
Cotton industry production statistics	1. Planted area (ha) - Irrigated 2. Planted area (ha) - Dryland 3. Yield (bales/ha) - Irrigated 4. Yield (bales/ha) - Dryland 5. Fibre Quality 6. Metric tonnes of cotton produced 7. Grower numbers 8. Average/median farm size

Economic value	9. Cotton price/bale ($/bale) 10. Gross value of the cotton produced in Australia ($) 11. Cotton exports % or $ by country (lint and seed) 12. Cotton's % of region gross value 13. Australia's % share of global cotton lint trade 14. Cotton proportion of global textile market
Profitability	15. Gross margin/ha 16. Income/ML water
Key aspect	**Social Indicator**
Education	1. Highest post school qualification of cotton growers
Employment	2.Number of people employed - farms 3.Number of people employed - industry 4.Number of people employed - regional
Workplace health and safety	5.Workers receiving regular health and safety training 6.Workers health & safety programs in place
Demographics	7.Grower age 8.Gender participation in industry
Social capital	9. Australian Cotton Conference delegate numbers 10. Financial membership in regional cotton grower associations
Innovation	11. Investment levels in R&D 12. Growers adoption of technologies
Legal compliance & responsibility	13. Fines imposed upon cotton SMEs by regulatory authorities

Results

Economic Category

The economic aspects considered were cotton production statistics, crop yield and quality, and its economic value. There are up to 1500 cotton farms in Australia with the average area of a cotton farm currently being 495 ha. On average for the last five years (2009-2014); the irrigated crop yield was 9.85 bales/ha (2236 kg/ha) and the dryland crop yield was 4.09 bales/ha (928 kg/ha). Australian yields are high by international standards, almost three times the world average. These yields reached record levels in 2012-13 at 10.73 bales/ha (2436 kg/ha). Production reached a record high in 2011-12 at 1,215,870 metric tonnes (5,356,254 bales) and a low in 2007-08 at 136,831 metric tonnes (602,780 bales) during the millennium drought. Yields have continued to move upwards from 1200kg/ha in the 1970s, through 1400kg/ha in the 1980s to 1600kg/ha in the 1990s and can now be greater than 2270kg /ha (10 bales/ha).

Cotton's contribution to productive landscapes can be measured by its contribution to regional economics. For example, between 1997 and 2011 the value of cotton as a percentage of total agricultural production was 30 to 60 percent in regions where it is grown.

Environmental Category

The environmental aspects considered were soil health, water use, groundwater, biodiversity, riparian land management, integrated pest management, pesticide use and greenhouse gas emissions.

The main changes in management of cotton soils have been an overall reduction in tillage, widespread adoption of controlled traffic, permanent bed farming systems and increased application of nutrients for higher crop yields. Most farmers believe soil health has increased. Improving fertiliser efficiency is a major research and extension priority.

Water is critical to maximise crop yields and fibre quality. Water productivity, measured using the Gross Production Water Use Index has improved from 0.79 to 1.14 bales/ML over the last decade. This has been achieved by both yield increases and more efficient water management systems. The whole farm irrigation efficiency index improved from 57 percent to 70 percent. The crop water use index is above three kg/mm/ha, which is high by international standards (Roth et al 2013).

Examples of landscape or farm diversity include on average cotton farms have approximately 40 percent of their land dedicated to native vegetation. Several studies have investigated wildlife and their habitats on cotton farms and found for example: more than 42,000 birds representing 45 species were found on farm water storages in the Gwydir Valley; 153 bird species were found in natural vegetation in the Namoi Valley, and 450 species of invertebrates have been recorded in one cotton field during the summer.

Comparing the five year averages for the periods 2008-2013 and 1998-2003, the cotton industry has achieved an 89 percent reduction in insecticide use. It has reduced from 5.12 kg to 0.55 kg active ingredient per hectare.

Nitrogen fertilisers and energy consumed are a major source of greenhouse gas emissions, particularly nitrous oxide, and the industry continues to invest in research, demonstration trials and decision support tools focused on improving nitrogen use and energy use efficiency.

Social Category
Key social aspects considered were education levels, demographics, employment, health, social capital, research and development and legal compliance. Education can be used as a measure of human capital. The number of cotton growers with a diploma level or above qualification has risen from 30 percent in 1990 to 50 percent in 2011. The number of growers holding a bachelor degree rose from 13.5 percent to 24.1 percent between 1991 and 2011.

The cotton industry has a strong research and development culture. Over the past 24 years, the Cotton Research and Development Corporation (CRDC) has invested $200 million in research, development and extension on behalf of Australian cotton growers and the Australian Government – delivering an estimated minimum $1.4 billion benefit back to growers on their farms, and twice that value to the wider community (CRDC 2014).

Cotton industry surveys show growers are innovative and adopt new technology readily. For example;
99 percent adoption of transgenic traits for insect and weed management, 82 percent adoption of new round module pickers, 70 percent of farmers use soil moisture probes, 90 percent using satellite navigation systems in tractors, 84 percent use a smart phone or tablet for accessing information about their farming system.
93 percent of farmers use integrated pest management (IPM).

Summary
Cotton agronomy has played an important role in "Building a productive, diverse and more sustainable landscape", (the conference theme). This paper used the cotton industry as a case study using a sustainability reporting process that with some minor modifications would be suitable for most agricultural situations.

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Identifying areas where coal seam gas development may assist agricultural intensification

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Abstract
The coal seam gas (CSG) industry has suffered criticism on numerous agriculture related issues. However, despite potential costs associated with CSG development, landholders could have opportunities from additional farm income from CSG contracts. Whilst there are initial studies on the macro level impacts of CSG on the economy, environment and community, there is limited information on the geographical extent of the overlap between agriculture and CSG and its impact on the physical and economic components of farms. This study aims to evaluate the inherent agricultural potential of the areas under CSG petroleum leases in the Surat Basin by identifying areas where aspects of CSG development may help facilitate farm intensification. This initial assessment and site selection process is part of a further research undertaking on the evaluation of the agricultural productivity and financial performance of the farm enterprises in CSG tenements.

Biophysical attributes (e.g. slope, pH, plant available water, and climate) were used to classify areas within the CSG tenements that share related biophysical characteristics. The comparison of the biophysical production environment of the CSG tenements and its existing land uses was used to provide a simplified indication of areas perhaps not currently supporting its potential land use and where CSG payment therefore could prove beneficial in farm improvement and assist in agricultural intensification and development. . Future work will now focus on these areas and on what opportunities may exist within them.

Key words
Coexistence, Fuzzy membership, GIS, raster input

Introduction

Agricultural expansion and intensification is being constrained by land use competition from other land developments (Fischer, Byerlee *et al*. 2011). While there are areas in Australia that are non-arable and can be devoted to other profitable industries such as mining and energy (i.e. CSG), these industries also thrive in fertile and agriculturally productive areas. Because of this, concerns have been raised regarding the threat of CSG to agricultural production.

However, given the diversity of the physical and agro-socio-economic characteristics of the farms in the Surat Basin, a common effect of CSG cannot be assumed. In some circumstances, despite potential reductions in farm income and increased farming costs associated with CSG development, landholders could gain benefits through significant inflow to net farm income from effective negotiations with energy companies. These financial opportunities could support agricultural intensification, especially when cash flow is highly variable.

This site (area) selection process provides information on the geographical extent of the overlap between agriculture and CSG and is being used to determine case studies for further research on determining whether co-existence between these industry sectors may either increase or decrease farm enterprise wealth based on the level of current and potential farm productivity. These areas within the CSG tenements in the Surat Basin are classified according to their current and potential land use in order to highlight areas where it may be most likely for CSG payment to facilitate agricultural intensification. Subsequent studies can target these areas for further investigation.

Methods

Study area

The study area includes the CSG petroleum leases or tenements within the Surat Basin region in Queensland, comprising 26,534.79 km^2 or 15 percent of the entire basin. The majority of this area is used for agriculture covering 88% of the total tenement area.

Spatial data preparation and analysis

Four biophysical characteristics were used in the study–slope, plant available water capacity (PAWC), soil pH, and aridity index. Percent slope was derived using the hole-filled Shuttle Radar Topography Mission (SRTM) (Jarvis, Reuter *et al*. 2008) Digital Elevation Model (DEM) data with spatial resolution of 3 arc-seconds (approximately 90m) . The Australian Soils Resource Information System (ASRIS) (CSIRO 2013) provided information for both the PAWC (0-100 cm) and soil pH (1:5 soil: C_aCl_2 solution extract) at a map scale of 1:250,000 having a raster resolution of 0.0025 degrees or approximately 250metres. The aridity index (annual rainfall: annual evaporation) represents the climatic environment with a raster resolution of 0.05 degrees (approximately 5km) obtained from the Bureau of Meteorology.

All spatial data were resampled to a 30m spatial resolution and converted into the Geocentric Datum of Australia (GDA) 1994 and projected using Map Grid of Australia (1994), Zone 55. The raster input data were subjected to fuzzification according to its strength of membership based on ASRIS, United Nations Environmental Programme (UNEP), and the Strategic Cropping Land (SCL) criteria.

Fuzzy Membership

In the study, the raster data of biophysical attributes comprising PAWC, slope, soil pH, aridity has been assigned to its appropriate set using a specific fuzzification process in ArcGIS (ESRI 2014). The following fuzzy membership functions for each biophysical variable were used:

- For the PAWC, fuzzy 'large' was chosen as the membership type. According to ASRIS, areas with soils that have PAWC of 20 to 40mm are considered to have low water holding. Values used in this criteria are indicative of the range of soil properties within the ASRIS dataset, though it should be noted that these are lower than reported by others (Dalgleish and Foale 1998) working in this region.
- In the western cropping zone, a slope of less than or equal to 3 % is considered suitable for cropping, while for other zones, a slope up to 5 percent is acceptable (Shaw 2011). The type of membership set for slope variable is called fuzzy 'small', slope > 5% would mean that its membership is approaching a value of 0, or having low suitability membership.
- Strategic Cropping Land guidelines suggest a suitable soil pH range of > 5 at 300mm and 600mm soil depth for all soils, but ≤ 8.9 for rigid soils (Shaw 2011). In order to capture these critical points, the fuzzy 'Gaussian' membership was adopted. This type of membership function transforms the input values into a normal distribution, with the crossover point (approximately set at pH 6.7) having the value of 1.
- Aridity index criteria for the study used the UNEP classification. This index indicates degree of dryness of the climate in a particular area. Those areas considered arid have an index of 0.03 to 0.2 while semi arid regions are between 0.2-0.5 index (UNEP 1997). A critical crossover point of 0.27 was chosen to arbitrarily cover the range of values in categorising aridity. Similar to PAWC, aridity variable adopted the fuzzy 'large' as membership type.

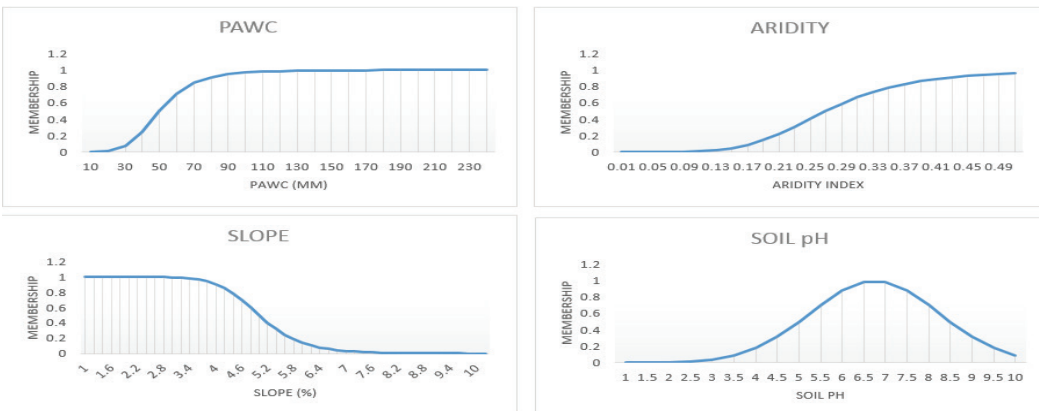

Figure 1. Fuzzy membership of biophysical variables

An overlay type method was adopted in which input fuzzy rasters were combined according to the least common denominator for the membership of all the input criteria, or the Fuzzy 'And'. The fuzzy overlay rule was executed by classifying the membership value as:

- 0 to 0.39 = low suitability for intensification
- 0.40 to 1 = high suitability for intensification

The fuzzification of the raster inputs was compared to the land use data derived from the 2006 National Land use map and Australian Land use and Management updated as of 2010 obtained from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (ABARES 2010). This allows the identification of areas with potential agricultural intensification and high productive value, and those in which additional source of funding could support agricultural improvement and development.

Results

Land use was used as a surrogate for agricultural production: cropping areas represent higher intensification of production, while grazing/pasture represent a lower level of intensification. In order to identify areas of interest, land use data were intersected with the fuzzy overlay of the biophysical areas and sorted according to their current and potential land use (Figure 2a). The boundaries of each group are the result of the overlay procedure and maybe subject to limitations, which thus provides this study with an initial and aggregate estimate.

Figure 2b shows the distribution of the areas of interest. The 'dark green' areas are grouped as HH or those cropping areas that have high current and potential intensification (top right of the matrix, Figure 2a). These areas depict the most suitable environment, based on the inherent biophysical parameters (slope, soil pH, PAWC, aridity). Further, being a cropping zone, it is has the highest potential for farm productivity and returns based on current input and farming management. These areas comprise nine (9) percent (209,848 hectares) of the total agricultural tenement of the study area. CSG payment would be used here to improve an already intensive agricultural system, possibly through increased efficiency or management intensity.

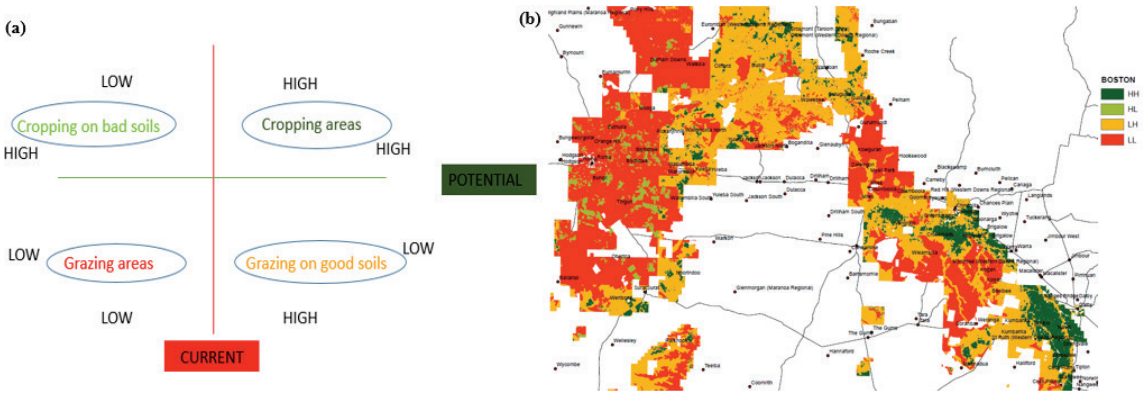

Figure 2a. Quadrant of level of intensification **Figure 2b. Level of intensification map**

The LL areas where current and potential intensification is low. These are grazing areas on marginal cropping land, less suitable for high value production (i.e. due to poor soil quality, low water availability). These 'red' zones (Figure 2b), constitute the largest portion of the agricultural tenements having 49 percent or a total of 1,140,872 hectares. CSG payment may be of use in improving existing land use rather than in changing it to something more intensive.

In between are the mixed classification of LH and HL. The LH are the 'yellow' regions in the map (Figure 2b) that have high potential due to the environmental conditions, but are currently grazed. This region (902,052 hectares or 39%) is inherently suitable for agricultural production according to the biophysical characteristics and the fuzzification process. While this land use is presently devoted to grazing, there may be scope to improve its returns through additional investment for its transition into cropping. It may be that CSG payment could be used in these regions to move toward a more intensive land use. On the other hand, HL are the 'light green' areas (73,477 hectares) that indicate current cropping in areas categorised as less

suitable for high value land use using the methodology described. CSG payment may assist in providing a more stable cash flow in these environments where current efforts for intensification may have risk.

It should be noted that only four biophysical attributes have been used in site classification yet,other local factors would also likely impact any future land use. Furthermore, all potential benefits from intensification would need to be weighed against the possible losses incurred due to CSG operations on the farm, and these are likely to be highest in the HH zones.

Conclusion

This study on the biophysical attributes of the CSG tenements as input to the site selection process of case study areas is a simplified indication into where CSG could have potential impact on agricultural productivity and financial performance of the farm enterprises. While some farmers may regard CSG operations as unnecessary to their farm enterprise, exploration of the level of productive potential of agricultural tenement reveals areas that could possibly increase their farm returns with more intensive agriculture or alternative farming system. It may be that farmers in these areas could utilise the financial support or compensation from gas companies as capital to develop and improve their farm by re investing in infrastructure and inputs. There are notable examples related to this, where farmers have chosen to use CSG payment or on-farm investment to improve their enterprise. Investigations into how this can be achieved will be undertaken in subsequent effort in this area. This study is a preliminary step in investigating this issue for the coexistence of agriculture and CSG. A series of case studies for the different regions highlighted in this analysis will be undertaken in future work to illustrate the benefit of CSG income in farm improvement.

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High intensity, short duration livestock grazing management improves landscape function, and increases species richness and abundance of ground-layer insects on grazing properties of the northern slopes and tablelands of NSW, Australia.

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Abstract:
Landscape degradation and biodiversity loss from livestock grazing is common. However, there are alternative approaches to grazing management that claim biodiversity benefits as well as reduced land use impacts. We compared contrasting management styles of livestock grazing on 16 properties (eight pairs). One property in each pair was managed using a form of high intensity, short duration grazing with extended pasture rest (HISD), while the comparison property was managed conventionally, in a way more typical of the region, usually continuous grazing, or with extended grazing periods. Unimproved pastures on each property were assessed for soil stability, water infiltration, nutrient cycling capacity and perennial grass cover, while parasitoid hymenopteran abundance and diversity were assessed as potential indicators of insect diversity.

All measures of landscape function and hymenopteran abundance were higher on properties managed under HISD grazing. Differences were significant for stability, infiltration and nutrient cycling capacity assessments, perennial plant surface cover and for parasitoid hymenopteran species richness.

Greater landscape function values indicate a greater capacity for soil to better support plant growth with increased perennial grass cover further improving landscape function (and potentially increasing soil carbon and organic matter levels). Increased insect diversity will enhance the provision of important ecosystem services including pest control, pollination, dung burial and nutrient cycling and provide food resources for native animals. This research suggests that there may be improvements in several ecological functions associated with HISD grazing and this may have benefits both for production and potentially for the conservation of native fauna in the landscape.

Key words:
HISD rotational grazing, invertebrates, perennial plants, parasitoid hymenopteran, Landscape Function Analysis

Introduction:
In Australia livestock grazing can lead to losses of native biodiversity (Yates et al., 2000) and it is important to identify grazing management methods that can ameliorate that loss. On the slopes and tablelands of the New England region in northern NSW changes in ground-layer plant species composition are common in response to livestock grazing when compared with un-grazed vegetation communities (Whalley et al., 1978, Tremont, 1994). Commonly alongside these vegetation changes there are also landscape degradation issues (Dorrough et al., 2004). Managing livestock grazing in a way that can reverse or halt biodiversity loss and improve landscape function may have benefits both for long-term production stability through improved ecological function as well as for conservation objectives in production landscapes (Dorrough et al., 2004).

In the late 1980's several producers in the New England region began adopting methods of grazing based on high intensity short duration (HISD) stock rotations (Earl and Jones, 1996). It is a common claim of this type of grazing management that there will be increases in biodiversity once management changes (Savory and Butterfield, 1999). This may benefit production, albeit indirectly, but it may also contribute to increases in biodiversity in the broader landscape. While there has been extensive research looking at comparative production figures of HISD types of management compared with more conventional practices (see reviews by Briske (2008) and Teague (2013)), and limited research into plant diversity changes in Australia (Earl and Jones, 1996, Kahn et al., 2010), there are substantial knowledge gaps in Australia with regard to insect diversity with HISD (but see Dorrough et al (2004) and Lindsay and Cunningham (2009)).

In this study we investigated how the species richness and abundance of parasitoid hymenopterans, a key insect group, differs among farm management regimes in the ground-layer of commercial grazing properties. These insects are considered to be good potential indicators of broader biodiversity (Anderson et al., 2011). Invertebrates (including insects) can have many indirect production and conservation benefits in an agricultural context. For example they play significant roles in ecosystem processes such as pollination, pest suppression, nutrient cycling and can influence soil structure significantly (Lavelle et al., 2006, Altieri, 1999). Invertebrates are also an important food source for native birds, frogs, reptiles and bats (Gullan and Cranston, 1994).

The results presented here are one component of a larger research project examining whether biodiversity in the ground-layer differs between properties managed with HISD grazing compared with the conventional, regional norm. As there is considerable variation in management practices on commercial properties, Landscape Function Analysis (Tongway and Hindley, 2004) was utilised to give an alternative (and objective) method of categorising properties, and also to determine whether there might be a relationship between grazing management type and landscape physical condition.

Methods:

Property selection: Eight pairs of commercial scale properties were selected for study. One of each pair was managed with high intensity, short duration grazing (HISD) with decisions to move stock based on plant growth and recovery. Commonly there was also a reduction in the use of external chemical inputs and hand-feeding on the HISD properties. The comparison property was nearby (often neighbouring) with management typical of conventional, regional normal practice, and although variable, were generally year-long continuous grazing or long duration rotations. The properties were managed at similar scales of commercial production.

Landscape Function Analysis: Landscape Function Analysis (LFA) (Tongway and Hindley, 2004) is a method that allows the objective assessment of soil health; a landscape with high functionality has a high retention of vital resources such as water, topsoil and organic matter that reflects the capacity of the soil to act as a suitable habitat for the growth of plants. Three sites on each property were selected to undertake Landscape Function Analysis. Within each pair of properties each transect had an equivelant transect on the comparison property in terms of soil type, aspect and slope. Perennial plant distributions were also assessed using the point-centred quadrat (PCQ) method (Tongway and Hindley, 2004).

Insect collections: Insects were sampled using a Sweep net in mid summer 2014. One hundred and fifty sweeps were taken from three sites on each property. Sweeps on the conventionally managed properties were collected in the paddocks where livestock currently grazed. On the HISD properties 150 sweeps were done where stock were currently grazing, 150 where they had most recently been grazing but had moved on from, and 150 where the stock were next to be moved to. This ensured that the theoretical amount of available forage was standardised (ie. plant biomass) on both management types. Insects were sorted to Order and Hymenopterans (excluding ants) were then identified to family level.

Analysis: Data was analysed using a linear mixed effects model using R (R, 2014).

Results and discussion:

Parasitoid hymenopteran species richness was high on the 16 properties, with 260 different species being identified from approximately 1000 individuals. The largest number of parasitoid hymenopteran species on any one property was 47 (HISD), and the lowest was two (conventional). There was a large amount of variation within management categories (see Fig 1A). However, despite such large variation in the number of species found on properties within a management category, species richness between management types differed significantly ($p=0.034^*$), with greater species richness being found on HISD properties: mean HISD/conventional = 29.5/17 species respectively. The abundance of parasitoid hymenopterans was also higher on HISD properties (Fig 1B) (mean HISD/conventional = 65.4/32.9 individuals respectively), but this difference was not significant ($p=0.197$). The highest number of individual parasitoid hymenopterans was 142 (HISD) and the lowest was three (conventional). Parasitoid hymenopterans are considered to be useful indicators of insect and plant diversity (Anderson et al., 2011), and where ecosystems approach greater complexity, the interconnecting food webs that they are an integral part of also become more complex(Tylianakis et al., 2007). Thus, higher levels of diversity of parasitoid hymenopterans on HISD

grazing properties may better support a number of ecological processes and services relative to the conventional, regional norm. Conversely, abundances of hymenopterans may be affected by outbreaks of relevant prey species.

It is notable that this data was collected during a time of severe dry, approaching drought conditions (mid-summer 2014). It may be that differences between management types are exacerbated under such conditions and it is expected that under more adverse conditions the greatest loss of biodiversity would occur (and landscape degradation).

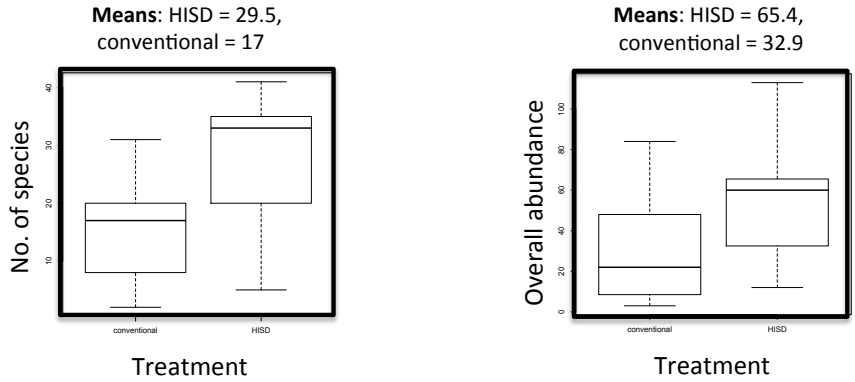

Fig 1. Boxplots showing differences in A) average parasitoid hymenopteran diversity (no. of individual species), and B) average number of individual hymenopterans on HISD properties versus conventional properties

All three LFA indices differed significantly between the two categories of property management (Fig. 2). The nutrient cycling indice showed the strongest difference between management types (means HISD: 83.1%, conventional: 75.5% (p-value = 0.006), with differences in stability and infiltration being weaker but still significant (Fig 2A and 2B respectively). Coverage of perennial grass cover (surface area (m^2)/hectare) also showed significant differences between management types (mean HISD = 48986m^2/Ha, conventional = 2845m^2/Ha, $p<0.01$**. Such large differences in perennial grass cover would have heavily influenced the landscape function values, especially infiltration and nutrient cycling capacity. Additionally levels of soil litter cover and micro-topographical differences were found to be generally higher on the HISD properties, and this would also have strongly influenced the three landscape function values.

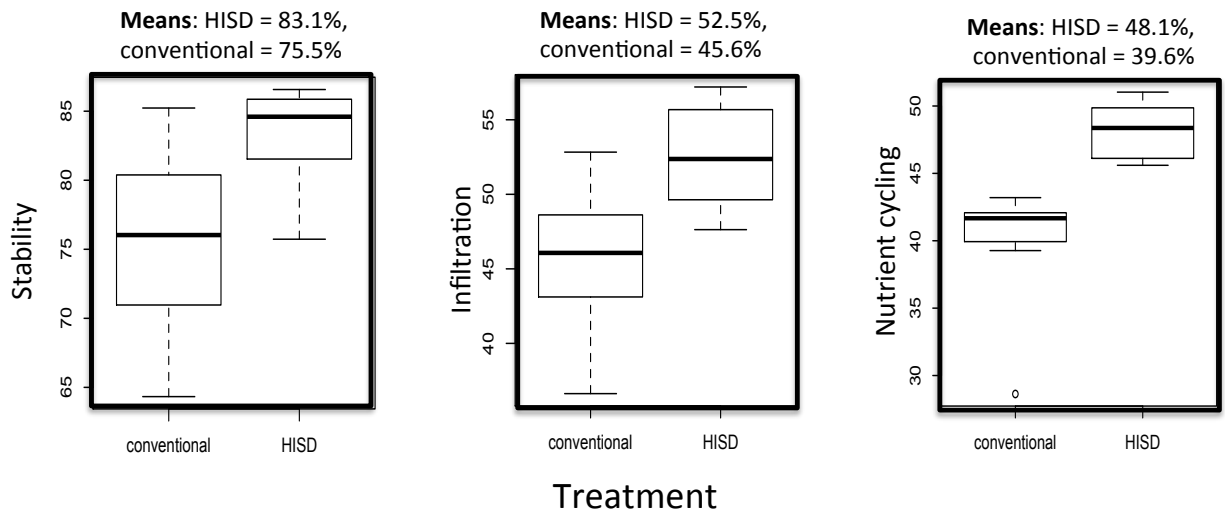

Fig 2. Boxplots showing the differences (out of a maximum of 100%) for each Landscape Function Analysis index. a = stability (p-value = 0.03*), b = infiltration (p-value = 0.02*), c = nutrient cycling (p-value = 0.01)**

Conclusions:
The results of this study show greater parasitoid hymenopteran species richness on properties managed under HISD compared with the conventional regional norm. These differences were despite considerable variation within one management type and varying length of time that a property had been managed with HISD. Additionally the strong relationship between management type and landscape function values, with higher values generally being found on the HISD properties suggests that there may be benefits for both production and conservation objectives where HISD management is undertaken. This research is one aspect of a larger project that will also examine plant diversity and plant community composition between the two differing types of management in order to gain an overall understanding of how biodiversity differs between properties managed with varying forms of HISD compared with the conventional, regional norm.

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Patterns of dry matter production, allocation and water use in perennial wheat

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Abstract
Perennial crops offer the prospect of flexible, diversified and stabilized farming systems, by contributing grain and grazing while protecting environmental services. Recently, perennial wheat derivatives developed between bread wheat (*Triticum aestivum* L. [6n]) and perennial grass (e.g. *Thinopyrum intermedium* [6n]) have been reported to survive, regrow and contribute grain in the field at Cowra NSW, for up to four years. This PhD project examined the performance of four perennial wheat derivatives, relative to annual wheat and perennial grass, under controlled and field conditions, over three years. Three experiments addressed patterns of dry matter production and partitioning over growth cycles, how they changed under source or sink limitation, and patterns of root growth and water extraction under prolonged water deficit. Perennials developed greater dry matter in successive cycles, especially root dry matter, relative to annually replanted bread wheat, with perennial wheat derivatives intermediate between annual wheat and perennial grass. Perennials showed greater root growth and water extraction capacity at depth in prolonged drought, in controlled conditions and in the field. Perennial wheats differed in the extent of these parameters, but the most promising derivative approached or exceeded the perennial grass. These results added to previous reports, showing how perennial wheat could regrow in subsequent years, with increased root growth allowing greater access to soil water, especially at depth, in controlled conditions and the field. These results confirm the proof of concept of perennial wheat, and that research on perennial wheat should continue.

Key words
Perenniality, dry matter allocation, regrowth

Introduction
Environment sustainability may be threatened in agricultural systems due to annual cropping, so perennial grain crops have been proposed to provide forage and grain in a more stable mixed-farming system, with greater flexibility and increased integration of livestock (Glover *et al*., 2010). This is especially important in Australia with variable rainfall and poor soils, in which water passing below the root zone of annual crops may contribute to water table rise and soil salinization. Recently, survival and yield of perennial wheat derivatives have been reported from field sites at Cowra and Woodstock (Hayes *et al*., 2012; Larkin *et al*., 2014), but data on dry matter and soil water were not reported. Consequently, this PhD study examined the patterns of dry matter production and partitioning over regrowth cycles under well-watered conditions. Subsequent experiments were done to examine how these patterns changed with source or sink limitation, and under prolonged water deficit, in order to further quantify the proof of concept for perennial grains.

Materials and methods
Together with one annual wheat (*Triticum aestivum* L., cv Wedgetail) and one tall wheatgrass (*Thinopyrum intermedium*, CPI-148055), four contrasting perennial wheat derivatives (OK7211542, CPI-147235a, CPI-147280b, 11955) were chosen from the 150 perennial wheat derivatives reported in field experiments by Hayes et al. (2012). In Experiment 1, large soil columns (360 PVC tubes, 150-cm long and 10-cm diameter), were sown in May 2011, thinned to a single plant, with the six genotypes replicated three times, to allow destructive sampling over three years. Annual wheat was re-sown in May 2012 and May 2013. Columns were watered fortnightly, fertilised monthly and weeded as needed. Partitioning of dry matter to root and shoot was measured through six sampling times. Samples were taken according to genotype phenology, at flowering (Oct-Nov 2011, physiological maturity (Nov-Dec 2011), at the end of dry season regrowth (April 2012 and 2013), and at end of the wheat growing season (Nov-Dec 2012 and 2013). At the end of each season, all of the remaining plants were cut to 8-10 cm from the soil surface. Root and shoot samples were

dried in a dehydrator at 70^{0}C and weighed. Further details of the experiments are provided by Aktar (2015).

In Experiment 2, the effect of source or sink limitation on root and shoot dry matter partitioning in third-year regrowth was examined in soil columns using four treatments as main plots, the same six genotypes as subplots, and three replicates. The four treatments were: 1) Control - as in Experiment 1; 2) Source - shade cloth was used to reduce incoming photosynthetically-active radiation (PAR) by ~70% after spike emergence; 3) Sink - spikelets were carefully removed from one side of each spike after spike emergence; 4) Both source and sink limitation – shade cloth and spikelet removal were both applied after spike emergence.

In Experiment 3, third-year regrowth was examined under prolonged water deficit in soil columns and the field. In soil columns, the experiment comprised two water regimes as main plots, the same six genotypes as subplots, and three replicates. Plants at maximum tillering were transferred to a rain shelter, and water was withheld from deficit columns until physiological maturity. To minimise water loss from the soil surface, a layer of 5-8 mm crushed fine gravel was applied to the soil surface. At harvest, each soil column was opened, the soil core was divided into 10cm depth increments, and gravimetric water contents were measured. For validation purposes, soil cores to 150 cm depth were also taken in March 2014 and 2015 from field experiments at Cowra, which were described in Larkin *et al*. (2014).

Results and discussion

Experiment 1

In the first year, average above-ground dry matter increased from 25 g/plant at flowering to 40 g/plant at maturity (Fig. 1). In the second year, average above-ground dry matter regrowth was only 15 g/plant in the dry season, but increased to 50 g/plant at the end of the wheat growing season. In the third year, average above-ground dry matter regrowth was only 8 g/plant but increased in the third wheat growing season to 110 g/plant. Below-ground dry matter increased each year, but was not recorded at harvest 5.

The annual wheat, Wedgetail, had consistent above- and below-ground dry matter in all wet seasons, when grain damage from birds was considered. The perennial grass, CPI-148055, was lower in above- and below-ground dry matter until dry season regrowth in the second year. By the second wet season, however, its above- and below-ground dry matter increased, and by the end of the third year, had doubled in above-ground dry matter and increased sixfold in below-ground dry matter, compared to annual wheat.

The perennial wheat derivatives accumulated more above-ground dry matter than annual wheat even in the first wet season. In subsequent wet seasons, the difference increased further. Highest above-ground (1 to 2 fold) and below-ground (2 to 5 fold) dry matter relative to annual wheat occurred in the third year.

The perennial grass CPI-148055 showed lower above- and below-ground dry matter compared to perennial wheat derivatives in the first year, but by the second year, more dry matter was partitioned below ground, so by the end of the second wet season, it showed the highest below-ground dry matter of all. In the third year, above-ground dry matter of CPI-148055 was comparable with the higher-producing perennial wheat derivatives CPI-147235a and 11955, but exceeded them in below-ground dry matter. These patterns for above-ground dry matter in soil columns were generally consistent with patterns of grain yield contribution in the field at Cowra (Larkin *et al.*, 2014).

Experiment 2

In the resown annual wheat, Wedgetail, treatment effects on above- and below-ground dry matter were not statistically significant, after grain damage from birds was considered (Fig. 2). In the perennial wheat derivative, CPI-147235a, above-ground dry matter was significantly reduced by source- or sink-limitation, and was reduced further by their combination, though root dry matter was not affected. In the perennial grass CPI-148055, source limitation reduced above- and below-ground dry matter, and sink limitation increased below-ground dry matter. No explanation is available for why the combination of source- and sink-limitation increased above-ground dry matter in CPI-148055 only.

Nevertheless, this experiment showed the perennial grass CPI-148055 invested more dry matter below ground, especially when the source-sink balance was changed by removal of half the spikelets. This

result was consistent with earlier reports that dry matter allocation patterns were different in perennials compared to annuals, and that perennial persistence will require a greater investment below ground for continued survival, regrowth and yield (Garnier, 1992). Experiment 2 is to be repeated with a wider array of germplasm and additional measurements, in order to further understand how source and sink priority may differ among annual wheat, perennial wheat and perennial grass, and among perennial wheat derivatives.

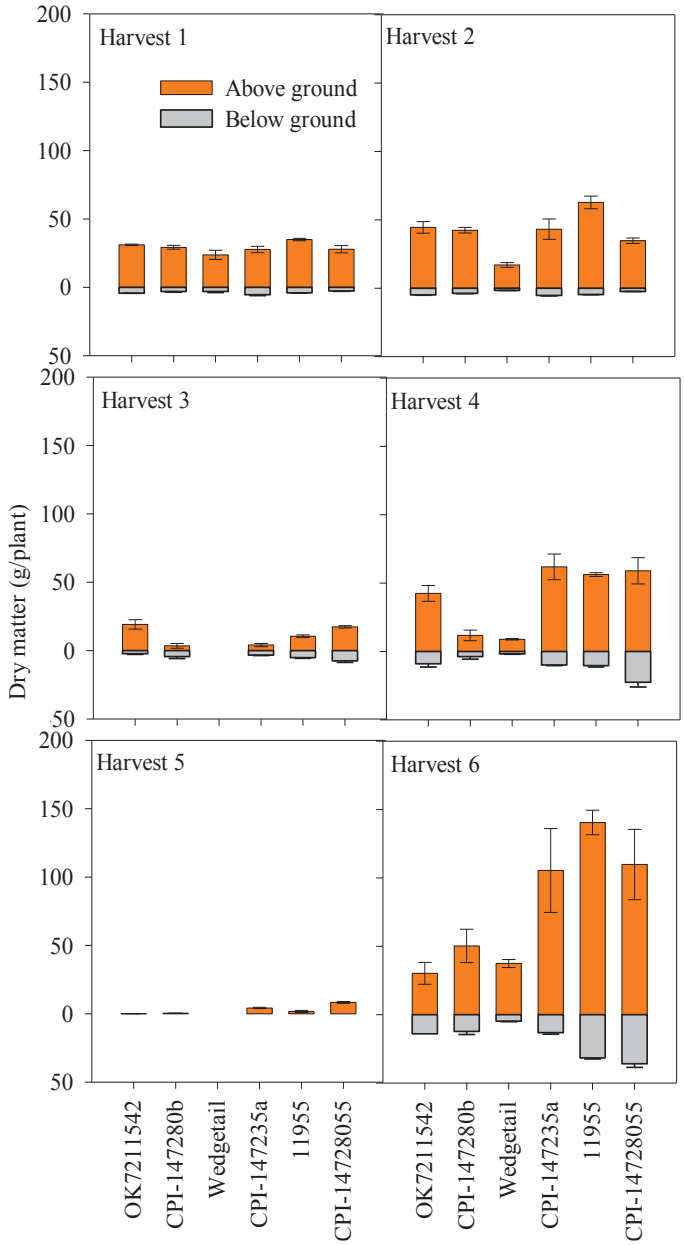

Figure.1. Above and below ground dry matter of four perennial wheat derivatives and one perennial grass and one annual wheat over six harvests throughout three years. In first year of plant age two harvest , harvest 1 (First wet season a) at flowering in October – November 2011, harvest 2 at maturity in November - December 2011 (First wet season harvest b) ; in second year of plant age , harvest 3(First dry season harvest) at the end of April 2012 and harvest 4 at maturity in November - December 2012 (Second wet season harvest) and in third year of plant age , harvest 5(Second dry season harvest) at the end of April 2013 and harvest 6 at maturity in November – December 2013 (Third wet season harvest). Sowing was done in May 2011 for all genotypes, only exception is resown annual wheat, Wedgetail, in May 2012 and May 2013.

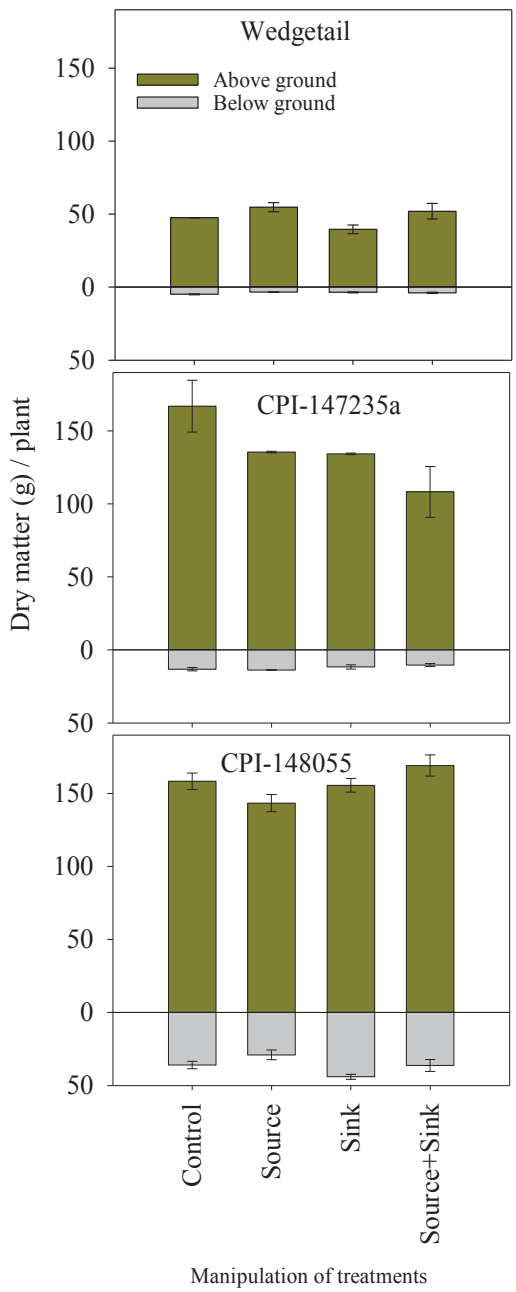

Figure. 2. Above- and below-ground dry matter of one perennial wheat derivative CPI-148235a and one perennial grass CPI-148055 in the third wheat growing season 2013, compared with annual wheat Wedgetail in the same season, in Experiment 2, under control, source limitation, sink limitation, or both source and sink limitation.

Experiment 3

At the end of the drying cycle (at 71 days after watering was withheld) annual wheat lost 7.3 % of column weight, while perennial wheat and perennial wheat grass lost 10.4 % and 9.2 %, respectively. The perennial wheat derivative CPI-147235a and the perennial grass CPI-148055 had more roots in the deepest soil layer and were able to withdraw water throughout the soil profile. In contrast, roots were absent in annual wheat in the 100-150cm soil layer, so was unable to withdraw water from deep in the soil profile. This was consistent with reported root depths of annual crops and perennial grasses (Gutierrez *et al.*, 2010; Lilley and Fukai, 1994; Zhou *et al.*, 2013). Likewise, in the field, the perennial grass depleted soil water content to 9.1 %, while the perennial wheat derivative CPI-147235a depleted it to 11.3 %, and wheat to only 12.7 % (SE = 1.3). There was evidence that depth of water extraction was limited to about 120 cm in wheat, while the perennials were able to use soil water from 150 cm depth, at the Cowra field site.

Conclusions

Over the 3 year period, perennial wheat derivatives invested in a greater root biomass compared to annual wheat, and their root systems were able to regenerate over growing seasons, which was similar in response to the perennial grass. More dry matter was partitioned below ground in the perennials, but especially in the perennial grass, and more so under sink limitation. This ability to persist and increase root biomass was associated with increased soil water extraction during the extended dry down treatment and the field, providing an environmental advantage as a result of perennial characteristics.

These results show that perennial wheat can regrow in subsequent years, with increased root growth allowing greater access to soil water, especially at depth, in controlled conditions and the field, which provides further proof of concept for perennial wheat. Research in perennial wheat should continue, in order to provide further options for farmers in future farming systems. For example, Larkin *et al.* (2014) have recently outlined a breeding strategy for perennial wheat, which would involve selection within segregating populations derived by intercrossing compatible *Triticum aestivum* L. [6n]/*Thinopyrum elongatum* [2n] derivatives. Growth analysis of perennial wheat derivatives should also continue, to relate dry matter production and allocation to grain and forage yield and water use in the field.

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Visualizing yield gaps in Australia's wheat cropping zone

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Abstract
Future global food security depends on producing enough nutritious food for a world population expected to peak at over 9 billion by 2050. Achieving this clearly depends, among other things, on realising the highest possible yields on existing farm land. Australian wheat producers have rapidly adopted new and improved crop management practices over the last 20 to 30 years. How much more can they improve their productivity? To answer this question we first need to know the current gap between potential and actual yields. Yet while average farm yield data have been well documented at local to regional scales, until recently there have been few comprehensive assessments of water-limited yield potential of rainfed crops in Australia. This paper describes the methodology used to calculate the gap between actual wheat yields and water limited potential yields in Australia's cropping zone. It then describes the interactive Yield Gap Australia website (www.yieldgapaustralia.com.au) that enables growers, agronomists, research funders and policy makers to visualise and delve into the extent and geographic distribution of the yield gaps. It also enables farmers and their consultants to benchmark their own farm against both average shire (SLA) yields and water limited yield potential adjusted for their soil type. We expect this website to be used for setting research and extension priorities and to inform agricultural policies to ensure a focus on regions with the largest unexploited yield gaps, and greatest potential to close them through sustainable intensification.

Key words
Yield potential, global food security, simulation, wheat, yield map

Introduction

The world's population growth and changing dietary requirements present a future global food security challenge. The FAO has estimated that global grain production will need to increase by at least 60% between 2010 and 2050 (Alexandratos and Bruinsma 2012) whilst growth in global grain production has all but stalled (Grassini *et al.* 2013). This presents a huge challenge for agricultural science and an exciting opportunity for the world's grain producers. One promising pathway to increasing grain production is to close the gap between yields currently achieved on farms and those that can be achieved by using the best adapted crop varieties with the best current crop and land management practices for a given environment (van Ittersum *et al.* 2013). Future global food security clearly depends on achieving the highest possible yields on existing farm land to protect our carbon-rich and bio-diverse forests, wetlands, and grasslands.

Australia contributed 12.1% of global wheat exports in 2005-2012 and has a significant role to play in making up for seasonal fluctuations in other global regions. Wheat is an important crop in Australia, being grown on 55% of the total cropland, which averaged 12.6 million ha between 1998-9 and 2011-12 (ABARES 2012). Overall, yields per hectare have not increased from 1998 to 2011. The first step towards closing the yield gap is to know its size and extent. Here we present the results of a high resolution analysis of yield gaps in Australia's grain belt and demonstrate how this information has been made accessible to Australia's grain growers, their consultants, research funders and policy makers. We discuss how this information might be used and speculate on the next steps in yield gap analysis.

Methods

This analysis is based on adapting, for the whole Australian wheat zone, a yield gap analysis method developed initially for estimating the wheat yield gap the Victoria Mallee region of Australia (Hochman *et al.* 2012). This method attempts to exploit all available soil, climate and crop data in the expectation that more detail will lead to greater accuracy. The first step in calculating the yield gap is to know where a crop is grown. For wheat in Australia, the National Land Use of Australia version 4 (2005-6); (ABARE-BRS 2010) data set provides data for a 'cereals' land use class at approximately 1 km pixel size.

Next we mapped actual annual wheat grain yields obtained by farmers (Ya) onto the land use map. For this we used the national agricultural data collated by the Australian Bureau of Statistics (ABS) at the level of statistical division (SD) annually, and at the finer scale of statistical local area (SLA) every five years when a census is carried out (Walcott *et al.* 2013). SDs are relatively uniform regions with boundaries determined from socioeconomic criteria. SLAs are based on local government areas, and are subdivisions of SDs. SLAs are the smallest administrative unit at which national crop yield data are available; however, since 1996 this has only been the case at five-yearly intervals in census years (1996, 2001 and 2006). For intervening years, only SD level data were available. Data on annual crop harvested area and average yields for the years 1996 to 2010 were sourced from ABS (2012). To derive SLA level estimates for each year, linear regressions were fitted to yield (t/ha) and crop area (ha) data for each of the 259 SLAs that grew more than 5000 ha of wheat from the 17 past census years from 1982 to 2010.

To determine water limited yield potential (Yw; yield that can be achieved under current best practice with well adapted commercial varieties and known technologies) we deployed the APSIM (Version 7.4) wheat model (Keating *et al.* 2003, Holzworth *et al*. 2014) which is well validated for wheat in Australia (e.g. Brown 2014) to simulate wheat grain yields, using 30 years of weather data from 3,913 SILO Patched Point data weather stations (Jeffrey *et al*. 2001) covering the grain zone at a median distance apart of 17 km. We assumed a 20 km radius as the nominal zone of relevance of each weather station and chose up to three dominant soil types per weather station using the ASRIS soil map (Johnston *et al*. 2003) to determine the most relevant soil types covering the cereal land use area in each 20 km radius zone. Typical soil profiles for each soil type were determined by averaging parameters of 434 deep soil profiles characterised in APSoil that had their Australian Soil Classification (ASC) identified. These 'typical soil types' were then used in the wheat simulations to represent the 3 dominant soils in each weather station area. Sowing rules and nitrogen fertiliser rules were used to ensure that yields were only limited by climate and water conditions. Simulations were run from 1981 to 2010 but because starting conditions for soil water were unknown, we only used the years from 1981 to 1995 to allow starting conditions to self calibrate over those years. Yw data from years before 1996 were discarded from the yield gap analysis.

The simulation results (>10,000 weather-soil results per year) were mapped for each year from 1996 to 2010 using local variogram kriging (Haas 1990) which was performed using the VESPER program (Minasny *et al*. 2005) to interpolate the Yw results over the whole cereal land use surface of Australia. These values were then aggregated up to SLA level for comparison with the annual average Ya values available for each SLA. Thus the independently estimated annual Ya and Yw values per SLA could be compared and the yield gap (Yw-Ya) and relative yield (Y% = 100 x Ya/Yw) were calculated and mapped.

The ultimate task was to develop a web based tool to enable users to visualize the spatial and temporal nature of Australia's wheat yield gaps and their components (as expressed by maps of Ya, Yw, Yg and Y%). In order to make these maps available to the public in an accessible and interactive form we adopted a user-centred approach. Following discussions with GRDC managers, CSIRO colleagues and a number of farmers and agronomists, we investigated other map based websites such as the GYGA site; and apps such as SoilMapp to help us develop our ideas about the basic design and functionality of the site. We captured these ideas in a PowerPoint presentation which was a mock up of the key functionality of the website. The PowerPoint mock up was then presented to two reference groups of farmers and advisers. These meetings were audio recorded and feedback was carefully considered in revising the design of the website. Prior to completion, the site was demonstrated to a number of GRDC managers for feedback before it was published online on the 9th February 2015. On that date GRDC panel members were invited to inspect the site and provide their feedback, both as users and based on their intimate knowledge of different parts of the grain zone. This and all subsequent feedback is captured in a spreadsheet which will be maintained as a record of feedback and the actions taken in response.

Results and Discussion

The yield gap of rainfed wheat in Australia in the period between 1996 and 2010 was derived by calculation of average wheat yield (Ya) at 1.74 t/ha, with a water limited yield (Yw) of 3.48 t/ha and a yield gap of 1.74 t/ha. Thus Australia's grain-growers are achieving on average 50% of their water limited yield potential. These average values are subject to large spatial and temporal variability and the interactive Yield Gap Australia website (www.yieldgapaustralia.com.au) now enables growers, agronomists, research funders and policy makers to visualise and delve into the extent, annual variation and geographic distribution of the yield gap. Figure 1 is provided to illustrate how the maps can be interrogated to provide detail at an SLA, Agro Ecological Zone (AEZ) and regional scale by simply pointing at the map. Similar maps and details can be shown for each of yield gap components, for specific years or for any decile year type. To relate this

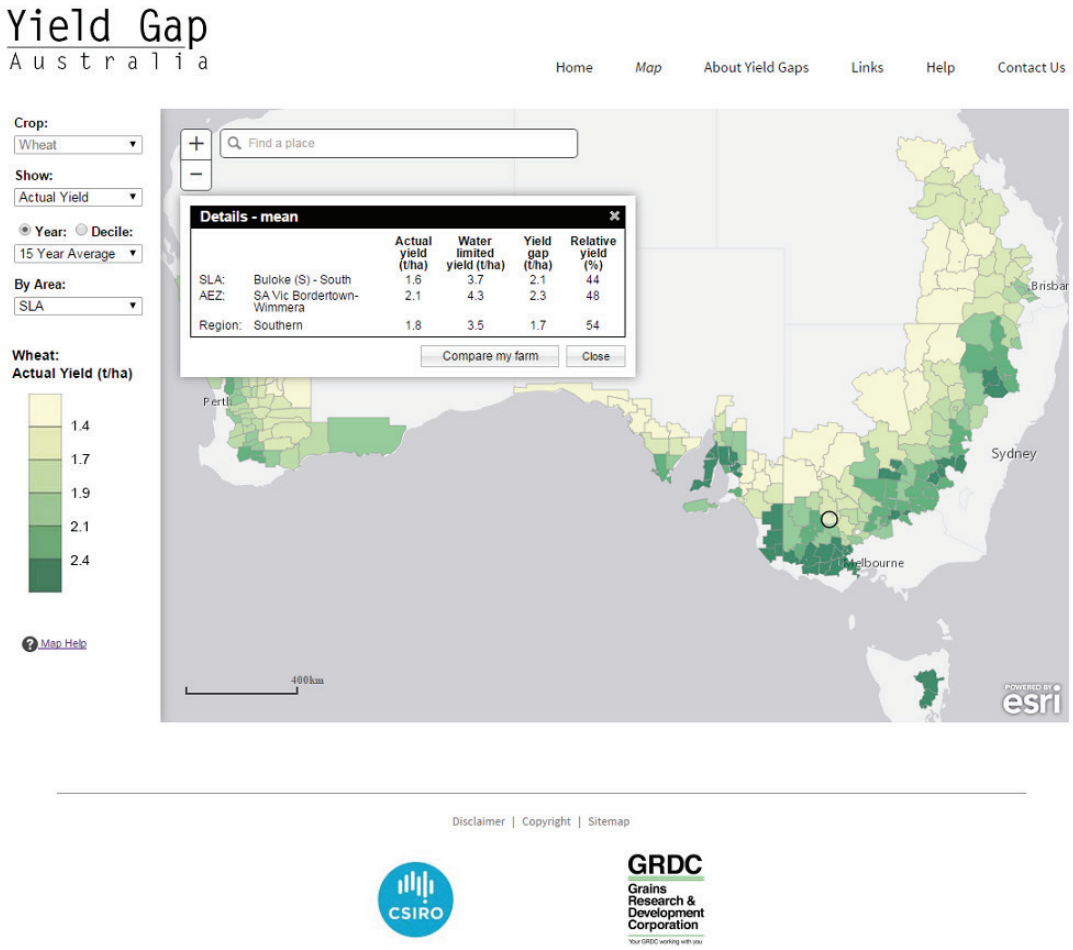

Figure 1. Map of Australia's average actual yields in the 15 years between 1996 and 2010 showing details for the Buloke South SLA (denoted by open circle) in a pop-up window.

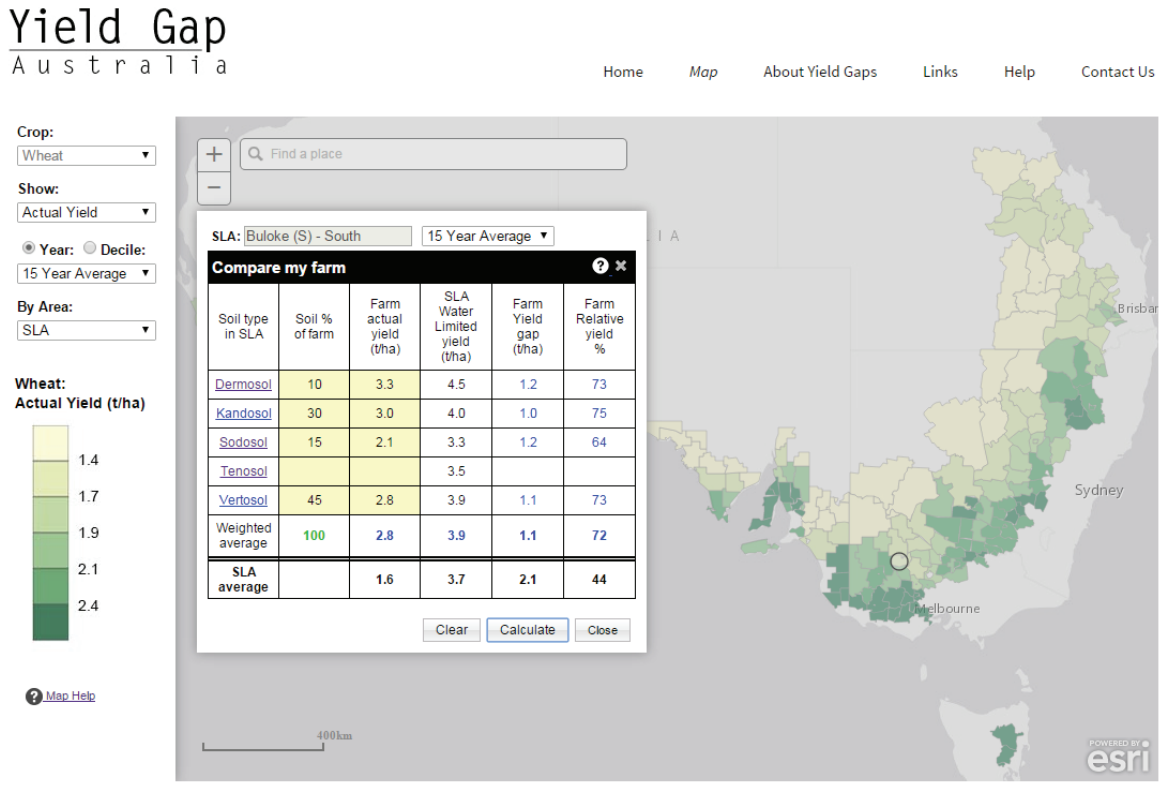

Figure 2. Compare my farm feature for a single farm in the Buloke South SLA that is achieving 72% of Yw.

information more specifically to a particular farm, users can launch the 'compare my farm' tool from the details box and enter farm-specific data that enables the user to benchmark their soil specific yields against both local averages and their water limited potential (Figure 2). In the Figure 2 example this fictitious farm is achieving yields well above the SLA average and at 72% of Yw which is close to the exploitable yield ceiling of 75-80% for rainfed crops.

The 50% yield gap result for Australian wheat is consistent with the results of other studies. At a sub-farm scale, Oliver and Robertson (2013) showed relative yields below 50% on 31% of a farm. At a regional scale, Hochman *et al*. (2012) reported a regional mean of 52.7% for the Wimmera in south eastern Australia over 20 years. A survey of progressive farmers in Australia's northern grain zone, covering 193 crops grown between 2005 and 2008, reported that that yields achieved were 65% of their water and nitrogen limited yield potentials (Hochman *et al*. 2014). Stephens *et al*. (2011) reported mean water use (production) efficiencies of 52.4% (1996-2000) and 51.1 (2003-2008). The highest relative yields reported for Australian wheat farms include a study of leading growers nationally (2004-2008) with relative yields of 77% (Hochman *et al*. 2009), and a study of three leading farmers over 16 to 20 years showed relative yields of 74% to 82% (van Rees *et al*. 2014). Data collated from over 5000 field/years between 1996 and 2010 were used to ground truth these maps. The results (to be published elsewhere) were highly consistent with the annual Ya and Yw values of their SLAs and provide further support for the validity of the yield gap analysis results.

Conclusion

The Yield Gap Australia website is an interactive map-based tool for visualising the extent and geographic distribution of the gap between actual and potential production of rainfed wheat crops in Australia. The website targets grain growers, agronomists, research funders and policy makers. Yield Gap Australia will be updated on an annual basis. It is envisaged that more crops (e.g. Canola) will be added to the website. Data are collected to ground truth Ya and Yw maps. Further work is required on the methodology of yield gap analysis and on utilizing the data produced in this analysis to investigate the causes of yield gaps in Australia. The maps provide an opportunity to investigate the absolute and combined contributions of individual causes of yield gaps such as subsoil constraints, fallow weeds, time of sowing and crop nutrition.

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Are future yield gains in wheat of 1.5% per year achievable?

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Abstract
Debates about the challenge of meeting global food security have emphasised the centrality of maintaining progress in crop yield. For the Australian grains industry we assess recent progress in wheat yield (the dominant crop) due to genetic improvement and advances in agronomy, and propose some of the emerging technologies that are likely to contribute to yield gain in the medium (10-20 years) term. Specifically, we assess the likelihood of reaching a target mean annual yield gain of 1.5% over the next 20 years.
With conservative assumptions about rates of genetic progress, on-going adoption of current and new agronomic technologies, we estimate that at a whole industry level, annual gains in wheat yields of around 40 kg/ha (1.5-2.0%) are feasible over the next 20 years.

Key Words
Adoption, technology, climate change

Introduction
From 2005 to 2012 Australia produced 3.5% of the world's wheat and 12.1% of the world's wheat export (ABARES, 2012). Future increases in grain production are likely to come more from intensification rather than bringing more land under agricultural production (Hochman et al. 2013). This paper explores the case for continued yield progress in the Australian grains industry, with a focus on wheat, the dominant crop. This paper is part review and part considered prediction. We estimate future yield progress in the medium term (20 years) at a whole-of-industry level, accounting for increased adoption of current technology and the development and uptake of emerging technology, that will close the exploitable yield gap (Hochman et al. 2012). We propose a target annual yield gain of 1.5-2% based on goals set by industry (GRDC 2012) and for Australian farmers to help meet the global challenge of achieving food security (Keating et al. 2014).

Review of contributions of genetic improvement and adoption of technology
We estimate the prospects for future yield progress comprising of improvements in underlying genetic potential, resource supply needed to realise that potential (most often attributed to improved agronomy, but also including the agronomy x genetic interactions), and accounting for the rate of adoption by farmers of improved cultivars and agronomic practices, which translates potential progress into realised progress on-farm. Here we briefly review these factors.

Impact of genetic improvement
Breeding progress has been reported at around 0.5% year^{-1} (Fischer 2009, Sadras and Lawson 2011). Various breeding and genetic technologies will be required in conjunction with conventional breeding to lift genetic gains above 0.5%. Technologies such as genomic selection, disease resistance gene cassettes, apomictic hybrids, and C4 photosynthesis vary widely in their likely timing. Within the next five years cultivars with appropriate phenology for earlier sowing are likely to be available. Cultivars with enhanced transpiration efficiency, early vigour and long coleoptiles are expected to be available in the next 10 years. Further out, cultivars with tolerance to aluminium, salinity and boron; frost at flowering; and with enhanced nutrient use efficiency will be likely ready between 10 and 30 years hence.

Adoption rates of technologies
Robertson et al. (2015) presented a best estimate of the current and future potential levels of adoption of current management technologies by Australian grain growers, together with average benefits in yield and/

or cost savings (Figure 1). Current levels of adoption were based on national or regional surveys of grain growers. They found that levels of adoption by grain growers of current technologies span the full spectrum from around 10% (e.g. use of decision support systems for risk management) to 90% (autosteer and guidance on farm vehicles). There are a significant cluster of technologies that are currently adopted by 30% or less of grain growers and which we estimate could potentially be adopted by 70% or more. Potential future levels of adoption were estimated by us based on the framework described by Kuehne et al. (2015). Rapid and high levels of adoption are achieved with technologies that have clear benefits to adopters, are easy to learn, adopt and dis-adopt, and are applicable to a broad range of farmers. The adoption of a new technology is influenced by its' complexity, the difficulty of use and capacity to determine what the benefit is. An example of a complex technology is earlier sowing because realising maximum yield gains will require integration of innovation in genetics, agronomy, materials, and information technology to deliver gains that neither could in isolation. For example, the use of soil water sensors and seasonal climate forecasts will reduce riskiness around the decision to sow earlier than currently possible. Seed technology (e.g. coatings that delay imbibition) and seeding equipment of adequate sowing capacity along with cultivars with superior early growth characteristics will ensure more successful establishment across the entire farm. Appropriate phenology will allow the crop to flower within the optimal window that minimises damage to the crop by temperature extremes, aided by improvements in tolerance to frost and high temperatures. Crops will have higher yield potential and so appropriate agronomic packages (fertiliser, pest, weed, and disease control) will be required to exploit this.

Benefits of technologies

Robertson et al. (2015) summarised the benefits to yield and growing costs based on a review of studies where the increases in crop yield or decreases in growing costs were quantified (Figure 1). Many technologies generate around a 10% benefit, however there are around seven technologies that they identified that can generate 20% or more average benefit when adopted: timely sowing, amelioration of subsoil constraints, weed-free fallow management, seasonal climate forecasts, broader adoption of break crops, integrated weed management, and more frequent and widespread soil nutrient testing. Technologies that have a large capacity for increased adoption and large benefits are obvious candidates for promotion and extension with grain growers. In our analysis these include soil amelioration, timely sowing, soil nutrient testing, and seasonal climate forecasting.

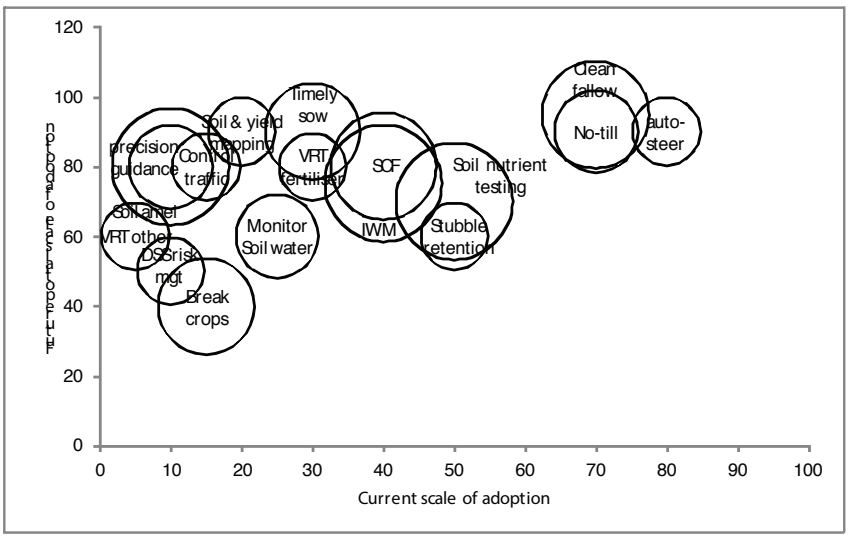

Figure 1: Gains in yield or cost saving expressed for key current technologies or practices used in the Australian grains industry. Points are plotted as the current level of adoption (% of Australian grain growers) versus the future potential level of adoption, with the diameter of the bubble representing the average percentage gain due to the technology or practice. SCF = seasonal climate forecasting, IWM=integrated weed management, VRT= variable rate technology, DSS=decision support system. See Robertson et al. (2015) for evidence of current and future levels of adoption and productivity gains.

Scenarios

We calculate the prospects for yield improvement over 20 years for whole-of-industry mean wheat yield (t/ha), with six assumptions.

1. Farmers vary in adoption of technology. The population of grain growers is considered as three groups comprised as top performers and early adopters of new technology (25% of land), a middle group (50% of land) who perform to the industry average and will adopt technology more slowly than the top group, and the bottom group (25% of land) who perform below the industry average and will not adopt new technology.
2. Farm consolidation. This contributes to gains in production through transfer of land ownership from below-average farmers to above-average farmers at a rate of 1% per year.
3. Based on the discussion above there is a conservative background genetic gain in yield potential at 0.5% per year, but its realisation will vary with farmer group due to adoption of high yielding varieties. Increased carbon dioxide concentration in the atmosphere makes an additional 0.2% contribution to increase in yield potential in a C3 crop like wheat (Fischer 2009).
4. Adoption of existing practices varies by farmer group. We assume that the top group has already fully-adopted a practice (such as variable rate fertiliser) that generates a benefit of 10% (or 0.2 t/ha), and the bottom performing group will never adopt it. The middle performing group moves from the current 20% to 100% adoption between years 1 and 10.
5. Adoption of a new and relatively simple practice varies by farmer group. An example would be a package of new agronomy and suitable cultivars for sowing 10 days earlier than currently practiced, worth on average 0.2 t/ha. Because these are relatively simple, the new practices are fully adopted by the top performing group between years 1 and 10. We assume that the middle and bottom groups will not adopt this as it is comparatively new, complex technology and relatively untested.
6. Adoption of a new and relatively complex practice varies by farmer group. We assume that the top performing group adopts this complex new practice/technology, but takes the full 20 year period to reach 100% adoption because it takes longer to develop and be adapted by farmers to their particular circumstances. This could be a practice that increases available soil water used by crops by 25 mm (equivalent to 20% or 0.4 t/ha), due to amelioration of a soil constraint or use of plastic mulch to reduce soil evaporation. The middle and bottom groups will not adopt this within the 20 year period as it is a comparatively new technology and relatively untested.

Results

The results in Table 1 show that over a 20 year period that with the above assumptions, yield increases from 2.0 t/ha to 2.8 t/ha, which is an average annual yield gain of 42 kg/ha/year or 2.1% and expressed relative to the year 1 yield and 1.5% when expressed relative to the year 20 yield. Because of farm consolidation the weighted yield in year 20 is similar to the yield of the top performing group because after 20 years this now comprises 44% of the total land area. The poor yield gain by the bottom group (5 kg/ha/year) does not influence the overall result significantly because there are only 5% of farmers in this category by year 20. A sensitivity analysis of the key parameters in this modelling exercise (data not shown) shows the annual yield gain varying from 32 to 50 kg/ha/year in response to variation in parameters. The rates of yield increase modelled here are consistent with recent historical yield gains of 30 kg/ha/year in South Australia and 40 kg/ha/year in Western Australia between 1980 and 2000 (Turner and Asseng 2005, Richards et al. 2014).

One of the largest contributors to future uncertainty about whether these yield gains are achievable is the impact of changes in the climate. Richards et al. (2014) show that yields in the Australian wheat industry are still increasing linearly between 1890 and 2010 both for the better (at 13 kg/ha/year) and drier (9 kg/ha/year) seasons, giving some confidence that improved genetics and practices are contributing to yield gains under both good and poor conditions. The most recent crop model estimates using climate projections from downscaled GCMs, assuming moderate to high emissions scenarios, incorporating CO^2 fertilisation effects, and allowing for some adaptation of sowing date, suggest that over the next 20-30 years there will be modest (<10% reduction) impacts on wheat yield potential (e.g. O'Leary et al. 2011). Other impact studies predict median wheat yield to decrease by up to 30% late in the 21st century under the most likely climate change scenarios. These impacts are significant, but 70 years hence, and are preceded by gradual changes over the next 20 years.

Conclusions

With conservative assumptions about rates of genetic progress, on-going adoption of current and new agronomic technologies, we estimate that at a whole industry level, annual gains in wheat yields of around 40 kg/ha (1.5-2.0%) are feasible over the next 20 years.

Table 1: Calculations of projected yield increase in the Australian wheat industry over 20 years. Groups refer to segments of the farmer population varying in their production performance and adoption of existing and new technology.

	Farmer group			
	Top	Middle	Bottom	Weighted all
Situation at year 1				
% of farmer population in each group	25	50	25	100
Yield (t/ha)	2.5	2.0	1.5	2.0
Between year 1 and 20 the separate contributions of:				
Genetic improvement (t/ha)[1]	0.35	0.20	0.09	0.45
Adoption of existing practices (t/ha)	0.00	0.20	0.00	0.29
Adoption of a new and simple practice (t/ha)	0.38	0.00	0.00	0.36
Adoption of a new and complex practice (t/ha)	0.20	0.00	0.00	0.28
Situation at year 20				
Yield (t/ha)	3.4	2.4	1.6	2.8
% of farmer population in each group	44	50	6	100
Overall net improvement				
Average annual yield gain (kg/ha/year)	45	20	5	40
Average annual yield gain (% of year 1 yield)	1.9	1.0	0.3	2.1
Average annual yield gain (% of year 20 yield)	1.4	0.8	0.3	1.5

[1] Including effects of CO^2 fertilisation

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Yield performance of temperate and tropical rice varieties in the Ord

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Abstract

Seven temperate and 20 tropical rice varieties, sourced from 9 countries (Australia, USA, Korea, Indonesia, Japan, India, Philippines, China and Vietnam), were evaluated in field trials for their yield performance in the Ord River Irrigation Area, during the dry season between 2009 to 2014. Two irrigation methods were tested, aerobic rice on raised-bed system compared with the traditional flooded system. Other agronomic features tested include date of planting, rate of sowing, rate of basal fertiliser, rate of topdressing, irrigation scheduling (aerobic only), and planting configuration (flooded only). A total of 23 individual trials were conducted over the 6-year period to test different hypotheses. Minimum air temperatures less than 15°C can affect varietal performance. Cold damage during the months of June and July warrants selection of varieties with cold tolerance for this environment, especially for the aerobic rice system. Ponded water provides a 4-8°C advantage over air temperature, thus providing some protection against such cold damage. This has resulted in higher yields under the flooded system. Planting dates, varying from late-February to late-May, can play a crucial role for plants to escape the low temperature damage at critical growth stages. Among the varieties tested, selected tropical varieties yielded higher than the temperate varieties. Yunlu 29 has been identified as the best variety adapted for aerobic rice system in the Ord. NTR 426 was found to outperform all other tested varieties under the flooded system in this environment.

Keywords

Variety × environment interaction, specific/wide adaptation, multi-criteria decision aids, PROMETHEE and GAIA methods

Introduction

Studies into adaptation of rice varieties to a range of environmental conditions are important to select varieties with yield stability and optimum grain production level. Adaptation is a complex process and very difficult to measure. The local environment, in which the rice plants grow, varies significantly from year to year. Crop management factors such as planting date, weed control, fertiliser application, and water management can also influence the growing environment. These factors can modify the length of the crop cycle, from seed to harvest, or the time taken by each variety to reach crop maturity. Variety by environment interaction, that is how each variety interacts with each environment, is the main focus in an adaptation analysis. The highest yielding variety in an environment may not be the preferred variety for that location. A variety's ability to produce consistently high yields, i.e. yield stability, at each location is more important. Since varietal performance is influenced by a range of factors, adaptation analysis is required to understand the complex variety by environment interactions. The overall objective of this analysis is to identify locally adapted rice varieties with good yield stability characteristics for the Ord River Irrigation Area.

Methods

Rice variety trials were conducted at the Frank Wise Institute of Tropical Agriculture at Kununurra in northern WA from 2009 to 2014. Twenty seven varieties were tested over the six years during the dry season, which resulted in 23 environments. Varieties included 7 temperate and 20 tropical varieties, which were sourced from different countries (Table 1). Different environments were created by: the year in which the trials were conducted; irrigation method, raised-bed/flushed/flooded; planting date; rate of top dressing; and rate of basal dressing (Table 1). Variety by environment matrix for grain yield was unbalanced due to not testing all varieties in all environments. Mean grain yield of 27 varieties tested in 23 environments was analysed using preference ranking organization method for the enrichment of evaluations (PROMETHEE) and graphical analysis for interactive aid (GAIA) analysis as described by Sivapalan et al. (2007). Visual PROMETHEE 1.4 software was used for this purpose (VPSolutions 2013). Data for aerobic (raised-bed and flushed) system and flooded system were first analysed separately to identify specific adaptation of varieties

for each system. Analysis of combined data was performed to identify broad adaptation of varieties for both systems. The PROMETHEE II Complete Ranking based on the net preference flow (Phi) was used to rank the varieties.

Table 1. Number of varieties used in each trial which created a unique environment

Varieties	Origin	Environments*																							
		09-FO-135	10-FO-053	10-FO-082	10-RB-090	10-FU-098	10-FO-098	11-RB-108-050	11-RB-108-100	11-RB-108-200	11-FO-108-050	11-FO-108-100	11-FO-108-200	12-RB-123	12-FO-123	13-RB-112	13-RB-128	13-RB-141	13-FO-112	13-FO-128	13-FO-141	14-RB-137	14-FO-141-525	14-FO-141-310
Temperate																									
Amar	Australia	●	●	●	●	●	●	●	●	●	●	●	●												
oo	Australia	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
Quest	Australia	●	●					●	●	●	●	●	●	●	●										
Doong	Australia	●	●					●	●	●	●	●	●	●	●					●	●				
ara	Australia							●	●	●	●	●	●							●					
Langi	Australia			●	●	●	●							●	●	●	●	●							
Jarrah	Australia													●	●										
Tropical																									
Fin	Australia							●	●	●	●	●	●	●	●										
Lemont	Texas, USA		●	●	●	●	●	●	●	●	●	●	●	●	●										
Tachiminori	Japan		●	●	●	●	●	●	●	●	●	●	●	●	●										
Vandana	India		●	●				●	●	●	●	●	●												
Milyang 23	Korea		●	●				●	●	●	●	●	●												
Muncul	Indonesia		●	●				●	●	●	●	●	●												
Takanari	Japan		●	●				●	●	●	●	●	●	●											
Pandan	Indonesia		●	●				●	●	●	●	●	●	●	●				●	●	●				
Pandan	Indonesia		●	●				●	●	●	●	●	●												
B6144F-MR-	Indonesia							●	●	●	●	●	●	●											
IR72	IRRI, Philippines							●	●	●	●	●	●	●	●										
NTR 426	IRRI, Philippines							●	●	●	●	●	●	●	●				●	●	●		●	●	
PSBRC 9	IRRI, Philippines							●	●	●	●	●	●												
ULP R17	Philippines							●	●	●	●	●	●												
Yunlu 29	Yunnan, China							●	●	●	●	●	●	●	●	●	●	●				●			
IR 64	IRRI,													●	●										
NTR 587	Philippines													●	●				●	●	●		●	●	
Viet 1	Vietnam													●	●				●	●	●				
Viet 4	Vietnam													●	●										
Viet 5	Vietnam													●	●	●	●	●							

* first two digits represent the year; FO=flooded; FU=flushed; RB=raised-bed; three digits after the alphabet represent calendar day of planting; last three digits represent three different rate of top dressing in 2011 and two rates of basal dressing in 2014. IRRI=International Rice Research Institute.

Results and discussion

GAIA uses Principal Components Analysis and the resulting bi-plots are shown in Figures 1 and 2. Each variety is represented by a point in the GAIA plane. Varieties with similar performance are closer to each other. The position of individual varieties on the bi-plots for the aerobic and flooded systems is different. This is due to the environmental conditions that prevailed in the aerobic system being different to that under the flooded system. Since most axes for the environments are aligned to the right, most favoured varieties are located on the right and least favoured ones on the left. There is no clear separation of temperate varieties from tropical varieties for their performance in both aerobic and flooded systems. In decreasing order, varieties Yunlu 29, Tachiminori, B6144F-MR-6, Quest and Langi were identified as best adapted to the aerobic system. Similarly, varieties NTR 426, Jarrah, ULP R17, Tachiminori and PSBRC 9 were identified as best adapted to the flooded system, in that order. Quest, Langi and Jarrah are temperate varieties from NSW. Among the top performing five varieties, Tachiminori is the only variety common for both systems.

Considering all the varieties tested, the rank order shows that selected tropical varieties seem to outperform most of the temperate varieties. It has been observed that night time air temperatures below 15°C can negatively influence growth and yield of rice at this location. However, ponded water in the flooded system can provide some degree of protection against such low temperatures. Therefore, cold sensitive varieties, such as NTR 426 and NTR 587, are ranked lower for the aerobic system and ranked higher for the flooded system. They are positioned on the right for the flooded system but on the left for the aerobic system.

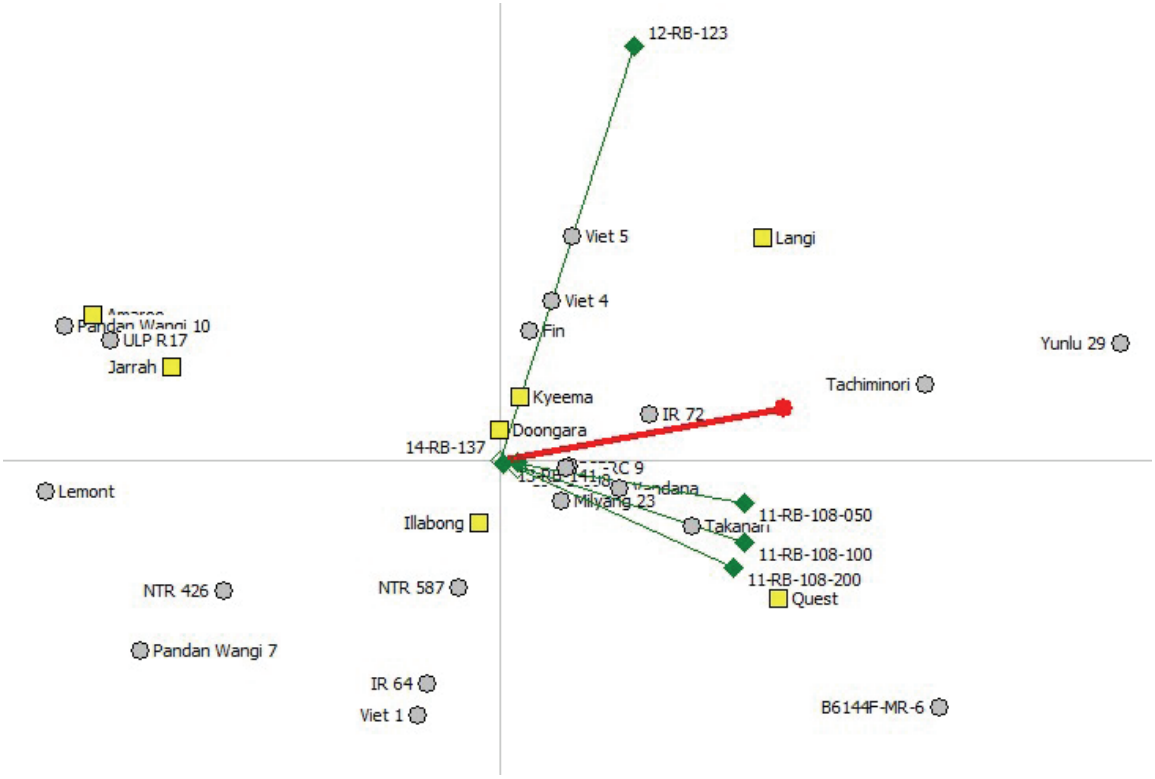

Figure 1. GAIA plots of varieties and environments for aerobic system. Green=environments, yellow=temperate varieties, grey=tropical varieties, red=decision axis.

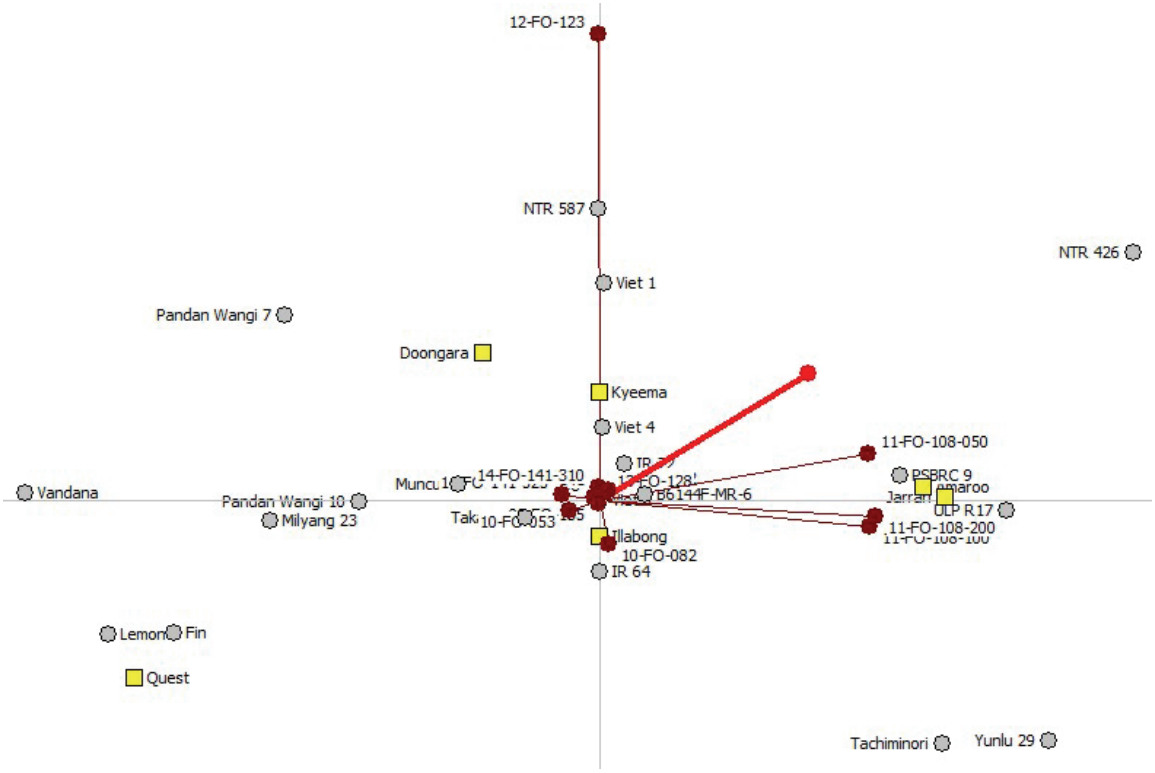

Figure 2. GAIA plots of varieties and environments for flooded system. Brown=environments, yellow=temperate varieties, grey=tropical varieties, red=decision axis

Each environment in Figures 1 and 2 is represented by an axis drawn from the centre of the GAIA plane. The orientation of these axes indicates how closely the environments are related to each other. For example, the three rates of top dressing in 2011 created environments which were similar for both aerobic and flooded systems. However, the environments in 2011 and 2012 were different as their axes are located away from each other. Date of planting failed to identify a pattern among the environments. This may be due to other factors, such as low night temperatures, which dominated each variety's performance. The length of the environment axis is also relevant; the longer an axis the more discriminant the environment. It is the case in 2011 and 2012 when the number of varieties tested varied from 17 to 20 which were higher than in other environments (Table 1). Thus the environments in 2011 and 2012 were more discriminant in this investigation. The orientation of an environment axis indicates where the best varieties for this environment are located. Note that varieties Kyeema, Illabong, IR 64 and Viet 4 were tested only in 2012, therefore they are aligned with these environment axes. Other notable cases are where Takanari and Quest which align with environment axes 11-RB-108-100 and 11-RB-108-200, respectively. This may suggest that Quest requires higher rate of top dressing than Takanari in the aerobic system.

The decision axis (thick red axis in Figures 1 and 2) is a representation of the weighting of the environments. Thus shorter decision axes are less reliable. The orientation of the decision axis indicates which environments are in agreement with the PROMETHEE rankings and which are not. The top ranked varieties Yunlu 29 and Tachiminori are located along the decision axis for the aerobic system, and NTR 426 for the flooded system. These varieties exhibit good yield stability across a range of environmental conditions. A combined analysis of aerobic and flooded systems could identify varieties adapted to both systems (Yunlu 29, Tachiminori, B6144F-MR-6, Langi and PSBRC 9 in that order) at the expense of maximum potential yield achievable in each environment. Therefore, for economic reasons, varieties with specific adaptation to each system must be considered rather than broad adaptation for both systems. Therefore, among the tested varieties, Yunlu 29 for the aerobic system and NTR 426 for the flooded system seem better varieties suited for the Ord River Irrigation Area. Grain quality must be tested before undertaking large area production with the selected varieties.

Conclusion

The yield performance of temperate and tropical rice varieties tested in this study was influenced by the environmental conditions imposed by factors such as growing season, water management, date of planting and basal and top dressing. Aerobic growing system was found to be completely different compared with flooded system in discriminating the varieties. Broad adaptation of varieties for both systems was considered as not preferred for economic reasons. Varieties with specific adaptation to each system have been identified for the Ord River Irrigation Area. Varieties originated from tropical regions might be better suited for this region compared with varieties from the temperate regions. Cold air temperatures during the night is a major issue which may impact the selection of appropriate varieties with cold tolerance. Grain quality of each variety under different environmental conditions needs to be evaluated before undertaking commercial plantings in the region.

Acknowledgements

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Biotic and abiotic factors affecting potato yields in Canterbury, New Zealand

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Abstract
Potato yields in Canterbury have remained static at c. 60 t/ha for the last decade. In contrast, potato growth models predict potential yields of up to 90 t/ha, which have previously been achieved by some commercial growers. A two-year project conducted by industry and research partners has examined factors constraining crop yields. In year 1, 11 processing crops were intensively monitored (final yield, plant health and soil quality assessments) throughout the growing season. Soil-borne diseases (*Rhizoctonia* stem canker and *Spongospora* root infection) were identified as consistent factors in reduced yields, along with subsurface soil compaction and inadequate irrigation management. Cropping histories that included potatoes within the last 10 years resulted in faster onset of symptoms of *Rhizoctonia* stem canker (by emergence), compared with fields with periods of grass growth and no previous potato crops (8 weeks after emergence). In year 2, a controlled field experiment in a commercial crop (known to have high levels of soil-borne pathogens) attempted to isolate and quantify the impacts of soil-borne diseases on yield. Treatments included soil fumigant (90, 112 and 146 kg/ha chloropicrin), in-furrow application of azoxystrobin (1.5 l/ha) or flusulphamide (400 ml/ha), and a nil pesticide control. Soil-borne pathogen DNA tests before and after treatment showed a slight reduction in DNA levels of *Rhizoctonia solani* and *Spongospora subterranea* in the soil (plots treated with fumigant), but results were very variable. Final total fresh yield averaged 58 t/ha and did not differ between treatments. Throughout the season, the severity of *R. solani* on underground stems was consistently less for the azoxystrobin treatment compared to all other treatments.

Key words
Solanum tuberosum L., Rhizoctonia solani, Spongospora subterranea, irrigation, fumigation, crop survey

Introduction

Yields from processing potato crops in Canterbury are currently static, at c. 60 t/ha paid yield (Pyke 2014). Computer-based potato yield modelling shows that yields of 80 to 90 t/ha are achievable if optimum growth conditions (climate, fertiliser, pest and disease control, irrigation) prevail, yields which have been previously achieved by some growers (Jamieson et al. 2003; Jamieson et al. 2006). This highlights a yield "gap" of c. 30 t/ha in current production, which could be caused by abiotic and biotic stresses. Jamieson *et al*. (2006) showed that nitrogen supply can limit potato yields, but previous research has shown that inadequate nutrient supply was not a major yield-limiting factor in Canterbury (Sinton et al. 2014). *Rhizoctonia solani* and *Spongospora subterranea* are soil-borne pathogens that have been shown to reduce commercial potato yields (Otrysko and Banville 1992; Hide and Horrocks 1994; Nitzan *et al*. 2010). *Rhizoctonia solani* causes stem canker and black scurf on tubers, while *S. subterranea* causes galls on roots and powdery scab on tubers. Both of these diseases have been commonly observed in Canterbury (Sinton *et al*. 2014). Inadequate irrigation management can also cause yield reductions (Jamieson et al. 2006). Soil compaction can also reduce potato yields through delayed emergence, restricted light interception and root development (Stalham *et al*. 2007). We summarise results from a 2-year project, including crop surveys and a targeted field experiment, investigating the factors responsible for the potato yield gap.

Materials and methods

Year 1 (2012-2013 growing season)

Processing potato crops (n = 11) ranging in area from 7 to 80 ha were intensively monitored throughout the growing season. The sites were located in Mid- and South Canterbury, New Zealand. Seven sites were planted with 'Russet Burbank' and four with 'Innovator'. For each cultivar, some sites had grown potatoes within the last 7 years, while other sites had not included potatoes in the rotation for at least 10 years. The sites were monitored for disease at 10- to 14-day intervals, from crop emergence to harvest. In each crop,

a representative observation plot, 10 m × 8 rows, was set up. At each visit, plants showing poor vigour or disease symptoms were also identified in other parts of the crop, the symptoms recorded, and the plants marked for final yield assessments. These were compared to healthy plants within the same crops (Wilcoxon paired test): 43 pairs in eight crops for comparing early diseased plants with healthy plants; 12 pairs in two crops for comparing wilting plants, missed by irrigators, with irrigated plants; and a 2.5 m by four rows weedy and weed-free area in one crop. Agronomic data recorded in the observation plot included: soil tests for quantification of soil-borne pathogen DNA (Root Disease Testing Service, SARDI, Australia); emergence counts; stem and plant counts; tuber yield assessment at key crop development stages; canopy, underground stem and root system (including tubers) disease assessments; virus incidence (DAS-ELISA); soil physical properties (e.g. texture, aggregate size distribution and stability, penetration resistance); and root mapping (depth and horizontal distribution) and vigour assessments. At crop senescence, final tuber yield and tuber size distribution (frequency of tubers in these size ranges: <67 mm, 67-90 mm, >90 mm length) was measured in each observation plot by hand digging 2.5 m by four rows, and this yield was then related to the in-season observations of crop health at that site. Potential yield was estimated using a potato growth model (daily time step) which accesses local weather and crop management information to take up water and nitrogen from a simulated soil, grow a canopy, produce biomass and distribute it among its organs. The model is sensitive to shortages of water and nitrogen (either slows leaf expansion or accelerates senescence).

Year 2 (2013-2014 growing season)

A replicated trial aimed to quantify the impact of soil-borne diseases on 'Russet Burbank' tuber yield and quality. The trial site had a cropping history that included potatoes within the last 10 years and was known to have large amounts of soil-borne pathogens. The soil treatments included a control (nil pesticides), three different rates (90, 112 and 146 kg/ha) of chloropicrin applied 3 weeks before planting, azoxystrobin (1.5 l/ha Amistar®) and flusulphamide (400 ml/ha Nebijin™) applied in-furrow at planting. The aim was to reduce all pathogens in some areas of the crop (chloropicrin treatments) and retain individual pathogen populations in others (azoxystrobin against *R. solani* and flusulphamide against *S. subterranea*), to estimate their individual and combined impacts on yield and tuber quality. Soil samples were taken before and immediately after the treatments were applied and tested for the presence of soil-borne pathogen DNA. The trial was a randomised block design with six treatments within each of three replicates (18 plots). Each plot was 130 m × 6 rows. Within each plot, five sub-plots assessed the effects of the treatments on plant growth and development. Agronomic information was collected every 10 days, including: incidence and severity of diseases affecting the crop canopy, root systems and tubers; yield and number of tubers; and crop cover using a Greenseeker® radiometer 505 Handheld sensor (NTech Industries, Trimble Navigation Ltd, Westminster, CO, USA). Incidence and severity of *R. solani* stem canker (RSC) were scored using the proportion of disease coverage on each plant stem (1 = no stem canker, 2 = 0-20% of stem area affected, 3 = 20-50%, 4 = 50-80%, 5 = >80%, or 6 = dead stem); and the form of the symptoms (1 = brown stem "speckling", 2 = speckling and solid brown lesions, or 3 = solid brown lesions). A severity × symptom score was calculated as the product of the severity and symptom type scores; e.g., a stem with >80% area affected by solid brown lesions scored 15 (5 × 3), and a dead stem scored the max, 18 (6 × 3). *Spongospora subterranea* galls on stems and roots were rated as: 1 = <5 galls/plant; 2 = 5-20, or 3 = >20 galls/plant. Final tuber yield and size distribution assessments were carried out after canopy senescence by hand digging a10 m^2 area in each plot. Data were analysed by Analysis of Variance (ANOVA) using GenStat (14th Ed, VSN International Ltd).

Results and discussion

Year 1

The average paid yield across the 11 crops was 55 t/ha, after an average deduction of approx. 10% by weight due to undersize tubers. The potential yield (paid) predicted by the model for that season was 87 t/ha, and the yield difference ("yield gap") ranged from 20 to 42 t/ha. At 90 t/ha, fresh gross yield (43 pairs of plants) was the greatest in sections of the crops where soil compaction, *S. subterranea* root galls or RSC were absent (Figure 1). Increasing severity of these diseases and the presence of soil compaction progressively reduced yield, and the smallest yield (30t/ha) where all three factors occurred. Soil- and/or seed tuber-borne diseases, along with the presence of soil compaction, were the most prevalent factors associated with yield reduction. Soil compaction zones were found in six of the 11 crops between 20-30cm below the ridge top and very close to the seed tuber position. Penetration resistance in these zones varied from 1 to 4.8 MPa and previous

has shown that potato root growth slows significantly beyond 1.5MPa (Stalham *et al*. 2007) . Few roots were found beneath these compaction zones, except where sub-soiling had taken place.

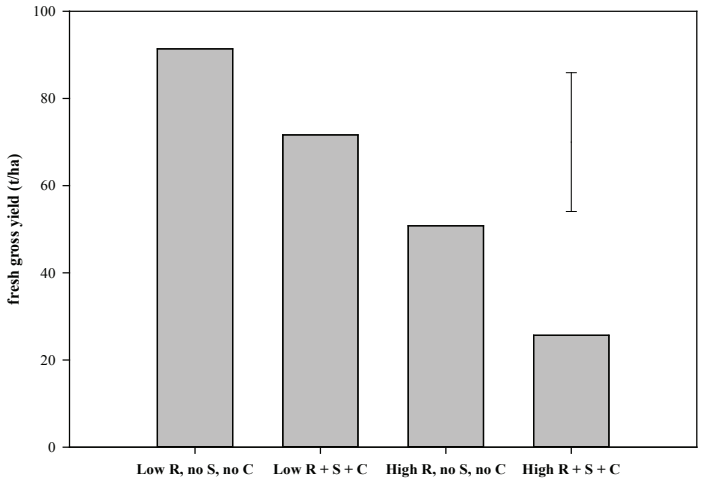

Figure 1. Averaged fresh "plant yield" from targeted areas in 11 potato crops. Categories are: "Low R, no S, no C" = low *Rhizoctonia* stem canker (RSC) incidence, no *Spongospora subterranea* root galls and no soil compaction; "Low R + S + C" = low RSC incidence, with *S. subterranea* root galls and soil compaction; "High R, no S, no C" = high RSC incidence, no *S. subterranea* root galls and no soil compaction; "High R + S + C" = high RSC incidence, with *S. subterranea* root galls and soil compaction. Bar represents LSD (5%) with approx. 76 df.

RSC occurred in all of the crops (but not in all plants), and *S. subterranea* root galls were also found in five of the crops. Inadequate irrigation management caused 13-28% yield loss (12 pair-wise comparisons). Poor weed control (a 15% yield loss was measured in a heavily infested area of one crop) also contributed to the yield gap in one crop. All five crops with *S. subterranea* root galls were in compacted soils, suggesting a link between poor water percolation and the presence of the disease. Whether or not potatoes were previously grown in a field did not directly affect yield in the 11 crops in the year of study, however levels of disease were related to history as well as the types of crops previously grown. Where grass had been grown the year before and potatoes were not part of the cropping history, the onset of RSC was delayed by up to 8 weeks. Conversely, annual crops grown the year before plus a recent cropping history of potato resulted in RSC symptoms showing at emergence of the current potato crop.Very low incidences of Potato virus X, Potato virus Y, Potato virus A, Potato virus M, Potato virus S and Potato leafroll virus were measured in most of the crops. This indicates that virus diseases were unlikely to have affected yields in the surveyed crops. Furthermore, these results were expected as the use of early generation (4th and 5th) seed tubers is common in Canterbury (S. Clelland pers. comm., 2012).

Year 2

Before fumigation or pesticide application, the amount of *S. subterranea* DNA averaged 1400 pg/g of soil across the treatments. There were slight reductions in *S. subterranea* DNA after the application of chloropicrin (all three rates) to an average of 1100 pg/g of soil, although this reduction was not significant (P = 0.06). Before application of the treatments, amounts of *R. solani* AG2.1 DNA (responsible for RSC) was highly variable and ranged between 250 to 700 pg/g of soil. Quantities of *R. solani* AG2.1 DNA were significantly reduced by the low (90 kg/ha) and medium (112 kg/ha) rates of chloropicrin to 150 pg/g soil (P = 0.002). The range of R. solani AG2.1 DNA quantities measured in the trial area was similar to that measured in most of the 11 crops surveyed in Year 1, but quantities were greater for *S. subterranea* compared with the five crops in Year 1 where the pathogen was present). Even though variable, the pre-treatment pathogen DNA results were consistent with anecdotal evidence that the field was likely to be highly diseased and therefore suitable for this type of experiment. Throughout the season, there was increasing incidence and severity of diseases caused by *R. solani* and *S. subterranea* in all treatment plots except those receiving azoxystrobin. Plants in the azoxystrobin-treated plots had less RSC (P = 0.013) than the other treatments (final mean severity × symptom score = 9 for azoxystrobin treatment cf. 13.5, mean of all other treatments (Figure 2). Final tuber yield did not differ between treatments (P = 0.782), which averaged 58 t/ha. This was attributed to the lack of control of soil-borne diseases, coupled with a severe hail storm in late February, which reduced canopy cover and hastened senescence.

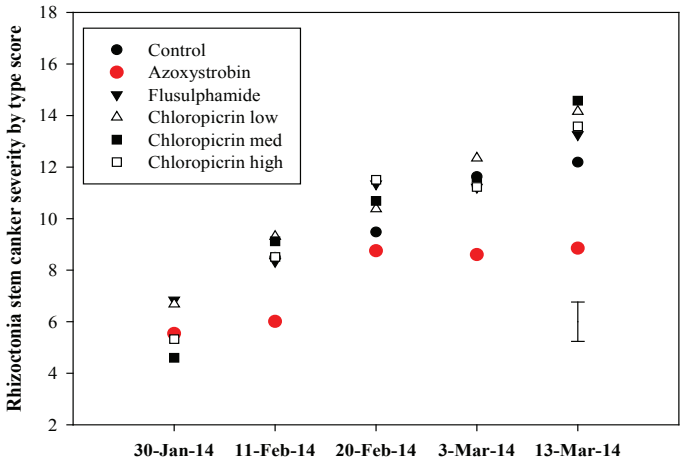

Figure 2. Mean *Rhizoctonia* stem canker severity scores (at different times during late crop growth) for potato plants grown in plots treated with different pesticides (cf. Materials and methods). Bar represents LSD (5%) with 10 df.

The lack of major disease reductions from the pesticides treatments may be explained by several factors. The treatments may have been ineffective because of poor soil penetration by fumigant, the local *R. solani* population was insensitive to azoxystrobin, and/or the diseases were too severe. Additionally, pathogen re-introduction may have occurred from surrounding untreated areas. Three rates of chloropicrin were tested in the experiment because this chemical had not been previously tested in commercial potato crops in New Zealand. Conditions were considered optimum at the time the chloropicrin treatments were applied.

Conclusion

This yield gap study of processing potato crops in Canterbury suggests that soil-borne diseases, in conjunction with soil compaction in the potato root zone, are likely to be the main factors reducing crop yields. Inadequate irrigation management and poor weed control were also identified as yield-limiting factors in some crops. These factors are also likely to be responsible for yield variability within individual crops. They can have cumulative impacts on potato yields and they can interact with one another. For example, soil compaction and excessive irrigation provide favourable conditions for development of soil-borne diseases. To reduce the yield gap, potato growers need to place more emphasis on a total package of best management practices. These would include: selecting clean cropping sites (no previous history of disease), optimising irrigation, fertiliser and foliar disease management to grow an unstressed crop. Future work should focus on improving soil health through crop rotation, improved irrigation management, and reducing soil compaction.

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Source-sink manipulation in canola (*Brassica napus* L.) indicates that yield is source limited

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Abstract

Understanding the source-sink relationship and its influence on yield is critical in developing strategies for breeding and managing crops for high yield. The aim of this work was to determine whether the yield in canola when grown in high rainfall area is limited by the sink or source. Six canola cultivars were grown in field conditions and a series of experiments were conducted to manipulate the source-sink ratios in 2010 and 2011, including complete defoliation of individual plants and early canopy defoliation, partial removal of flowers and pods at full flowering, 60% reduction in incoming solar radiation for 5 weeks by shading from the first flower and during the pod-filling period, and supplemental irrigation during pod-filling. The defoliation and shading experiments reduced seed yield by 17-26% because the imposed treatments significantly reduced sources. The partial pod removal and shading during flowering increased mean seed weight (MSW) as the source available to the remaining seeds was increased. Supplemental irrigation increased yield by 10% without reducing MSW. The findings from all the experiments indicate that canola yield is predominantly limited by the source availability. Therefore agronomic management and breeding should be directed to increase source available to crop throughout the growing season.

Key words

Source-sink relation, shading, pod removal, defoliation, supplemental irrigation

Introduction

Sensitivity of crops to source and sink manipulation has been used to investigate the critical period for determining grain number and to evaluate whether the yield is limited by sink or source during the grain filling period. In determinate crops such as wheat and barley, grain number is determined by anthesis and has little overlap with determination of grain weight, and therefore little competition for assimilates between determining grain number and grain weight. Canola is an indeterminate crop with a strong overlap in flowering, stem growth, branch growth, pod setting, and grain setting which is extended beyond flowering (Iglesias and Miralles, 2014). This overlap inevitably causes a strong competition for assimilates by different plant organs. Furthermore, canola experiences a rapid decline in canopy photosynthesis during the pod-setting and seed filling period as leaves senesce (Mendham et al., 1981). The competition for assimilates and decline in canopy photosynthesis activity may lead to yield of canola and grain number being more sensitive to assimilate supply. Despite this difference between canola and cereals, source–sink manipulation studies have focused on determinate crops such as wheat and barley (Calderini et al., 2006; Zhang et al., 2010). There have been few studies on whether the yield of indeterminate crops such as canola is limited by sink or source and the impact of sink and source limitation on yield at different growth stages under field conditions(Palta et al., 2008; Sandana et al., 2009). In southern Australia, canola has become the third largest crop and plays a significant role as a break crop in farming system. Understanding the sensitivity of canola to source-sink manipulation on yield and seed number can provide physiological knowledge for breeders to target breeding and for agronomist to adopt management practices to maximise yield. The aim of this study was to evaluate the sensitivity of grain yield and yield components of canola to source and sink manipulation at different growth stages and explore the implication of the source-sink relations to breeding and agronomic management to maximize yield in southern Australia.

Materials and methods

Six open-pollinated and hybrid spring canola cultivars (*Brassica napus* L.) were sown on 20 May each year (2010 and 2011) at Kojonup, Western Australia and grown under well fertilised conditions. A randomized split-plot experimental design was used to conduct defoliation at individual plant and canopy levels, partial pod removal at full flowering, shading at flowering and at the beginning of pod filling, and supplemental irrigation at pod filling. The genotypes were assigned in whole plot and the treatments in subplot. The

treatments were replicated 4 times each year. The plot size was 20 m by 1.54 m. The complete defoliation and partial pod removal experiments were conducted in individual plants (3 plants per plot) at full flowering. Canopy defoliation was also conducted at canopy (an area of 5 m by 1.8 m) levels at the 8 leaves stage. Shading at flowering was imposed for 5 weeks on an area of 2 m by 1.8 m using horticultural shade cloth when the first flower appeared. Shading at pod filling was imposed from the end of flowering (10% flowers remaining) to maturity. Shading reduced the photosynthetic active radiation by 60%. For supplemental irrigation treatment, 60 mm of water was applied to six genotypes in a micro plot consisting of an area of 1.8 m by 2 m within the whole plot. For the individual plant defoliation and pod removal experiments, individual plants were harvested. For early canopy defoliation, shading, and irrigation experiments, plant samples were harvested from an area of 0.54 m^{-2}. All samples were dried to determine yield and yield components. A split-plot ANOVA was performed to evaluate the impact of treatment on biomass, yield, harvest index, and yield components and the interaction between genotype and the treatments. Genotype was assigned in the whole plot and the treatments in the subplot. The means were compared using the LSD of the means, calculated from standard errors of the difference of the means using corresponding degrees of freedom.

Results

Defoliation caused significant reduction in all yield components except MSW with no interaction between genotype and the treatment. It reduced biomass per plant by 33% ($P < 0.001$), HI by 11% ($P < 0.001$), and yield by 33% (Fig. 1). The yield reduction was attributed to 26% ($P < 0.001$) fewer pods per plant, and 19% ($P < 0.001$) fewer seeds per pod rather than MSW (no change). Defoliation at the vegetative stage reduced biomass by 17% but increased HI by 7%. It reduced yield by 11% as a result of reduced pods m^{-2} rather than any effect on the number of seeds per pod and MSW (Fig. 1). The partial pod removal reduced biomass per plant by 24% ($P < 0.001$), HI by 14% ($P < 0.001$), resulting in a loss of yield per plant of 24% ($P < 0.001$) (Fig. 1). The removal of pods reduced the number of pods per plant from 133 to 80 while the number of seeds per pod remained the same, resulting in a 40% reduction in seeds per plant. This potentially increased the resource available to the remaining pods by 40%. In response to the increased source availability, MSW was significantly increased by 10% ($P < 0.001$) for all cultivars.

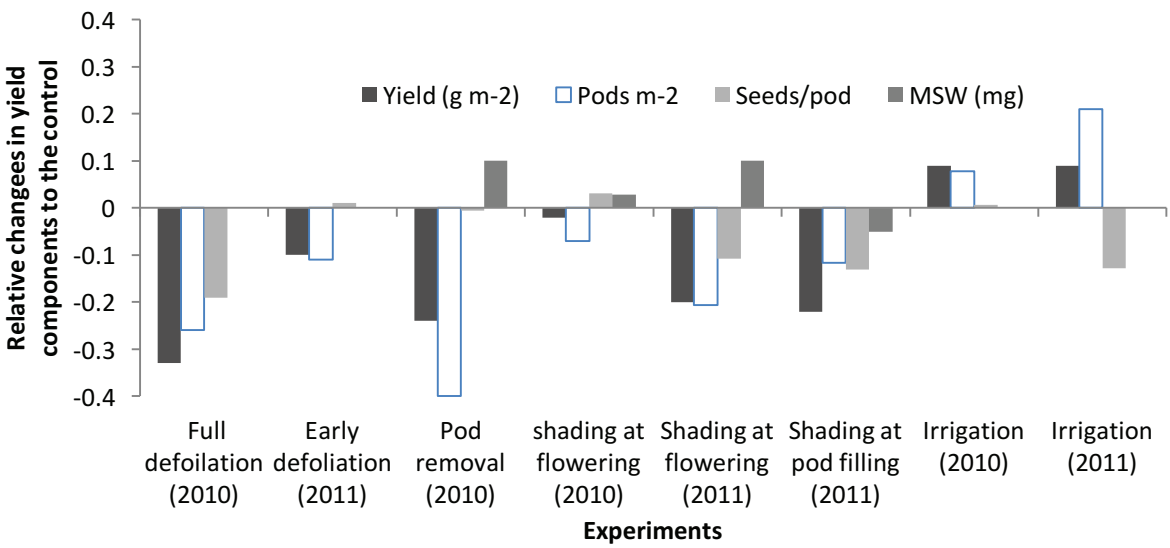

Fig.1 Relative changes in yield, pods m^{-2}, seed per pod, and mean seed weight (MSW) compared to the control treatment as a result of defoliation, partial pod removal, shading and supplemental irrigation in 2010 and 2011.

The effect of shading at flowering on yield and yield components differed between 2010 and 2011 (Fig. 2). In the extremely dry season of 2010, shading did not affect the number of pods m^{-2}, seeds per pod, and MSW, resulting in only 4% decrease in seeds m^{-2} and no yield difference (Fig. 2). In contrast, shading at flowering reduced pods m^{-2} by 21% ($P < 0.01$) and seeds per pod by 11% ($P < 0.01$) in 2011 (Fig. 1), resulting in a 29% ($P < 0.01$) reduction in sink size (seeds m^{-2}). In response to the reduced sink size, MSW increased by 10%. Shading at flowering reduced yield from 353 g m^{-2} to 269 g m^{-2} (Fig. 2). Shading at pod-filling led to a similar reduction in yield to shading at flowering, but their effect on yield components were different. It reduced seeds per pod by a similar percentage (11%) but pods m^{-2} by a smaller percentage (12%) than

shading at flowering. However, MSW was 5% ($P < 0.05$) lower than the control despite the reduced seeds m^{-2}. Over all, shading at pod-filling reduced biomass from 1035 g m^{-2} to 806 g m^{-2} and yield from 353 g m^{-2} to 261 g m^{-2} (Fig. 2a).

The additional 60 mm water supplied through irrigation increased yield by 9% ($P < 0.05$) (Fig. 2b), mainly from increased pod number ($P < 0.05$) in 2010 and 21% ($P < 0.01$) in 2011 (Fig. 1). It did not affect seeds per pod in 2010 but reduced seeds per pod by 13% as the number of pods increased in 2011 (Fig. 1). Overall, it increased sink size by 8% in 2010 and a 17% in 2011 as the number of pods m^{-2} increased. MSW was not affected by irrigation in both years (Fig. 1).

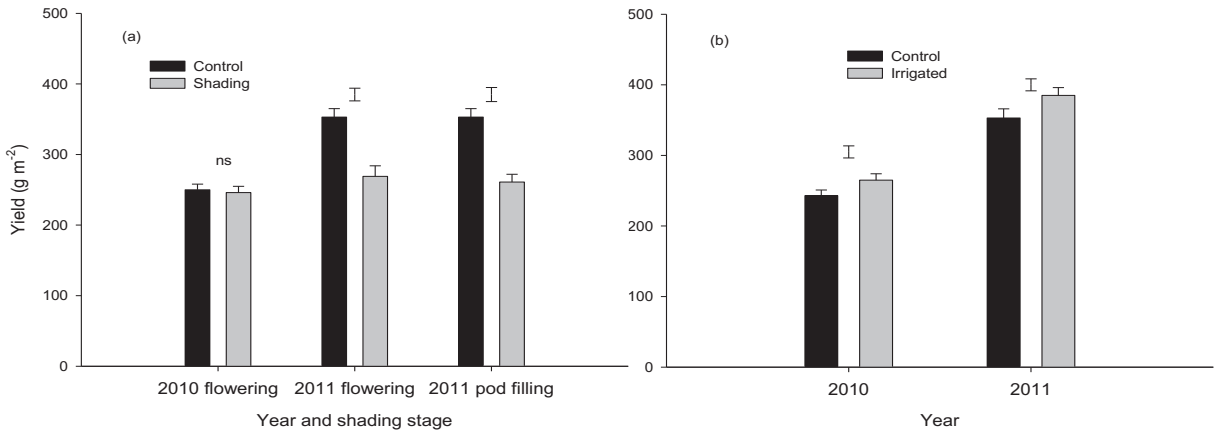

Fig 2. The effect of (a) shading at flowering and at podding on seed yield of canola in 2010 and 2011 and (b) supplemental irrigation of 60 mm at the end of flowering/beginning of pod filling in 2010 and 2011. The bars above the means indicate standard error and the lsd at *P* = 5% is shown between the bars.

Discussion

Altering the source-sink ratio either up or down provides evidence for our hypothesis that canola yield is more source- than sink-limited in the high-rainfall zone of southern Australia. When the shaded crop at flowering returned to the normal radiation level at the end of flowering, the crop appeared to have an abundant source available to the reduced number of seeds and resulted in significant increase in MSW. The increase in MSW in response to reduced sink size by shading at flowering and to the increased source by partial pod removal supports the source limitation hypothesis. Supplemental irrigation at the beginning of pod filling prolonged the flowering period, allowed more flowers to become viable pods and increased sink size by increasing the number of pods. In response to the increased sink, MSW did not decrease compared with the control. This further supports our conclusion that the control crop was under a source limitation. On the other hand, the lower MSW observed in the shaded crop at the pod filling stage indicates that assimilate supply was limiting even under the reduced sink size. Our conclusion under field condition is in agreement with the findings for individual plants in winter type oilseed rape under controlled environment conditions (Tayo and Morgan, 1979).

In contrast with many studies in determinate crops, this study showed that when the source was manipulated by shading, defoliation or supplemental irrigation, sink (seeds m^{-2}) was significantly modified (either reduced or increased) at the same time. This complicates the interpretation of results of source-sink manipulation, making source-sink relationships in canola much more complex than in the determinate crops such as wheat and barley. It is commonly assumed that seed filling was source-limited otherwise sink-limited if the magnitude of seed weight change was significant in the source-sink manipulation experiments (Borras et al., 2004). In our study, there was no significant difference in MSW between defoliation and the control, between supplemental irrigation and the control, and a small difference between shading at pod filling and the control. However, this lack of difference in MSW needs to be interpreted with care because the treatments significantly modified sink size (seeds m^{-2}), ranging from 23-40% fewer seeds m^{-2} mainly from the reduced pods m^{-2}. If the number of pods remained the same as in the control, MSW would have decreased by 11-27% by reducing the source supply. This indicates the canola crop could have been much more source-limited than indicated by the change of MSW.

The response of canola to the source-sink manipulation is in contrast to many studies in wheat in which yield was rarely source-limited (Borras et al., 2004; Calderini et al., 2006). The difference between canola and wheat could be related to assimilate supply between the two crops and to the competition for assimilates between plant organs. In wheat, the current photosynthetic assimilates contribute to 60-70% of yield and the stored water soluble carbohydrates (WSC) in stem and leaf sheath can provide 30-40% of yield (Foulkes et al., 2007). The reduction in assimilates from shading during the grain filling period can be almost fully compensated for by the stored WSC in stems under moderate source reduction, resulting in insignificant yield reduction (Zhang et al., 2010). For canola, the current photosynthetic assimilates contributed about 90% of seed yield and the contribution of stored water soluble carbohydrates to yield was around 10-12% (Habekotte, 1993). The reduction in assimilates to seeds under shading during pod-filling might have been significantly greater than the stored WSC and could not be compensated for by a relatively small amount of the stored WSC. In addition, during pod development and seed filling, the indeterminate feature of canola competes for assimilates to grow pods, stems, branches, and at the same time to fill seeds; resulting in high demand for assimilates. Therefore, it is unlikely that assimilate supply can meet all demands and therefore yield of canola is source-limited during the seed filling stage.

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Evaluation of commercial rice hybrids under local conditions in Battambang, Cambodia

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Abstract
In Cambodia, rice is the most significant crop. It employs at least 50% of the workforce and contributes 10% per annum to the GDP. Yields have slowly increased over the last 20 years at a rate of 3.9 % per annum. Average wet or rainy season yield of paddy rice in Cambodia is approximately 3 t/ha. The objective of this study was to evaluate the yield of seven hybrid rice cultivars, Arize BTE-1, Arize TEJ, HBO-2, HBO-5, HBO-8, PAC 837 and TH3-3 and one local open pollinated cultivar Chulsa grown under local conditions during the main rainy season in Battambang, Cambodia. All cultivars in this study produced yields above the country's average of 3 t/ha. Hybrid cultivars PAC 837, Arize TEJ and Arize BTE-1 were the highest yielding at 7.09 t/ha, 6.95 t/ha and 6.82 t/ha, respectively. Although hybrid cultivars were higher yielding due to hybrid vigour, yield from Chulsa at 5.6 t/ha was nearly double Cambodia's wet season yield average. Cost and availability of seeds as well as field location is a critical factor in determining cultivar selection. Proper management and fertilisation of local cultivars may increase yield at lower cost than hybrids.

Key words
Indochina, rice yield gap, sustainable intensification

Introduction

Cambodian rice production fell to an all-time low during the 1970s when the Lon Nol regime was in control (Nesbitt 1997). Since then rice production has rebounded. Between 1990 and 2013, crop and food production increased nearly fourfold, while cultivated areas increased by 50%, so that growth in agricultural productivity has been mainly driven by gains in crop yields. For example, rice yields more than doubled from 1.36 t/ha in 1990 to 3.16 t/ha in 2013 (Theng 2014). Despite the recent rise in rice yield, the average yield is well below that of neighbouring countries like Vietnam and China with access to hybrid rice varieties. Cambodia is home to over 3000 local varieties of rice, from which the Cambodia Agricultural Research and Development Institute (CARDI) recommend the planting of 34 varieties, which include aromatic varieties for different zones (CARDI 2013). Open pollinated varieties from IRRI dominate and account for about 85% of overall production. The preference of these varieties results from their agronomic characteristics that allows easy management of water and fertiliser (Yu and Diao 2011). The recommended varieties are IR66, IR72, Kru, IR Kesar, Baray, Chulsa, Rohat and the Rumpe, all derived from IRRI parent lines (Yu and Diao 2011). Hybrid rice is planted in all major rice producing countries except Cambodia. Super hybrids have been the focus of development in China since 1996. The three phase programme has focused on consistently increasing rice yields, phase one (1996-2000) achieved 7.5-8.25 t/ha, phase two (2000-2005) 9.75-10.50 t/ha and phase three (2006-2015) up to 13.50 t/ha (Li *et al.* 2009). There have been very few studies on the use of commercial rice hybrids in Cambodia for sustainable intensification. To date only one study has trialled rice hybrids in Cambodia during the dry season and indicated that Chinese hybrid varieties produced significantly higher yields of 6.92 to 7.75 t/ha, an increase of 23 to 38% over the local variety (Senpidao) in that experiment (Srean *et al.* 2012).

The objective of this study was to evaluate the yield of seven hybrid rice cultivars, Arize BTE-1, Arize TEJ, HBO-2, HBO-5, HBO-8, PAC 837, and TH3-3 and one local open pollinated cultivar Chulsa grown under local conditions during the main wet season in Battambang, Cambodia. This project aimed to determine which variety has the highest yield in the wet season as well as investigate the yield components that contribute most to grain yield.

Materials and methods

The temperatures in tropical northwest Cambodia range from a mean minimum of 21°C to 25°C and a maximum of 30°C to 36°C. There are two distinct seasons in Cambodia, a rainy season which starts in mid-May and can go until early October which is influenced by northeast monsoons and a dry season from November to March (Thomas *et al.* 2013). The rainfall peaks during the month of October at an average of 250 mm and is at its lowest at 17 mm in January. The experiment was laid out as a randomised complete block design (RCBD) with eight rice varieties and three replications. Seven commercial hybrids as well as a local open pollinated rice variety, Chulsa were grown during the wet season at the Don Bosco School Farm in Battambang, northwest Cambodia (13.1° N, 103.2° E; 18 m a.s.l.). The varieties range from early, to mid-early and mid-season maturity. The rice seeds were sourced through CARDI (Cambodia), Bayer group (Germany), Hanoi University of Agriculture (Vietnam), Advanta Limited (India) and Ho Bac Crop Variety Group (China) (Table 1).

Table 1. Source and maturity of the rice varieties.

Treatment	Rice varieties	Source	Maturity
T_1	Chulsa	CARDI (Cambodia)	Early
T_2	Arize Tej	Bayer (Germany)	Mid-early
T_3	Arize B-TE1	Bayer (Germany)	Mid-early
T_4	HBO 2	Ho Bac Crop Variety Group (China)	Early
T_5	HBO 5	Ho Bac Crop Variety Group (China)	Mid-early
T_6	HBO 8	Ho Bac Crop Variety Group (China)	Mid-early
T_7	TH3-3	Hanoi University of Agriculture (Vietnam)	Mid-early
T_8	PAC 837	Advanta Limited (India)	Mid-early

Rice seeds were direct seeded at 60 kg/ha on partially flooded blocks on 28th July 2014. All plots [30 m^2 (5 × 6 m) per plot] were kept flooded after germination to control weeds until two weeks before harvesting. Mechanically blended basal NPK fertiliser (15:15:15) was applied at 100 kg/ha on 28th August 2014. A second side-dress application of urea (46% N) was applied at 50 kg/ha on 8th September. At harvest, plant height, number of tillers, number of productive tillers, number of filled and sterile spikelets, 1000-grain paddy weight, grain moisture content, above-ground dry biomass and harvested yield per plot were recorded. The herbicide, Xpert70WP® (quinclorac, fenoxaprop-p-ethyl and pyrazosulfuron-ethyl) was applied at 20 g/ha, 5 days after sowing. Weeds were controlled by ponding with water levels at least 3 cm deep in the field for the whole duration of the experiment. Insecticide Super Amey® (chloropyrifos, cypermethrin and imidacloprid) was applied at 600 mL/ha on 9th August 2014 to control rice thrips and rice weevils. A fungicide Citty® (tricyclazole, isoprothiolane and carbendazim) was applied at 625 g/ha at the same time to control stem rot, damping off and rice blast.

Each variety was harvested on a different date due to different maturity times. Plant height, panicles and productive panicles of 10 randomly selected plants were recorded. Seed set was determined as the ratio of spikelets with grain to the total number of spikelets in the panicle and expressed as a percentage. The weight of the stems and leaves were recorded after drying for at least 5 days until there was no change in mass. The whole plot was harvested, the grain was threshed, dried to 14% moisture content and weighed. An analysis of variance (ANOVA) was used to determine the differences in grain yield and yield components between the rice varieties. Regression analyses were also carried out between yield components and total grain yield.

Results and discussion

PAC 837, Arize TEJ and Arize BTE-1 were the highest yielding hybrid varieties with a yield of 7.09 t/ha, 6.95 t/ha and 6.82 t/ha, respectively (Table 2). The lowest yielding cultivar was HBO-2, yielding only 4.5 t/ha. The difference between the highest and lowest yielding varieties was at least 2.6 t/ha or 37% yield difference. The open pollinated cultivar, Chulsa yielded 5.65 t/ha. The yields of the eight cultivars were significantly higher than the Cambodian average wet season yield of 3 t/ha. The highest yielding cultivar, PAC 837 had the highest 1000 grain weight at 27 g (Table 2).

Table 2. Grain yield and yield components
Means followed by the same letter(s) within the same column are not significantly different at the 5% level of probability.

Rice varieties	Grain yield (t/ha)	Plant height (cm)	grains per panicle	1000- grain weight (g)	Productive tillers per plant	Days to harvest
Arize BTE-1	6.82^{cd}	105.83^{de}	125.4^{bc}	24.72^{bc}	4.47^{bcd}	115
Arize TEJ	6.95^{cd}	108.24^{e}	140.4^{cd}	24.33^{b}	4.90^{de}	111
Chulsa	5.65^{abc}	90.23^{a}	88.9^{a}	24.37^{bc}	5.87^{f}	97
HBO-2	4.45^{a}	96.94^{b}	127.9^{bc}	25.23^{cd}	3.83^{ab}	83
HBO-5	6.50^{bcd}	90.13^{a}	143.7^{d}	23.14^{a}	3.97^{abc}	111
HBO-8	5.34^{ab}	100.48^{c}	176.2^{e}	25.73^{d}	3.37^{a}	111
PAC 837	7.09^{d}	101.00^{c}	112^{b}	26.97^{e}	4.63^{cd}	111
TH3-3	6.31^{bcd}	104.67^{d}	150.2^{d}	24.03^{ab}	5.60^{ef}	93
l.s.d (5%)	*1.36*	*3.39*	*15.81*	*0.90*	*0.71*	-

Although PAC 837 had an average of 4.6 tillers per plant, there were only two cultivars with significantly higher numbers of tillers; TH3-3 with 5.6 tillers and Chulsa with 5.9 tillers. Arize TEJ (108 cm), Arize BTE-1 (106 cm) and TH3-3 (105 cm) were significantly taller than the other cultivars (Table 2). The highest number of tillers was observed in Chulsa with a mean of 5.9 tillers but this cultivar corresponded to the lowest number of filled grains per panicle, producing a mean of 89 filled grains. Chulsa was also the shortest cultivar at 90 cm high.

Low correlations with grain yield were observed for plant height (R= 0.51), filled spikelets (R= 0.51), productive tillers (R= 0.30) and 1000-grain weight (R= 0.05) (Table 3) and only plant height was significant (R= 0.51, *P*= 0.01). Longer days to harvest generally resulted in higher yields (Table 3). In this study, rice plants with longer duration to harvest tend to grow taller and yield better than earlier maturing varieties. Although HBO-2 yields were low, the short maturity time could be an advantage to many growers. Maturing earlier than other cultivars enables a timely coordination of harvesting and delivery to mills for processing. In some provinces such as Takeo, Svay Rieng and Prey Veng which are prone to flooding, short duration cultivars such as HBO-2 and TH3-3 could be ideal for planting in these areas to avoid flooding at harvest.

Table 3. Relationship between rice grain yield and yield components/days to maturity.

Parameter	Equation	R	R^2	P
Plant height(cm)	y = 0.0715x - 0.9933	0.515267	0.2655	0.010
Filled spikelets per panicle	y = 0.0105x + 4.911	0.513225	0.2634	0.914
1000 grain weight (g)	y = 0.0452x + 5.0177	0.05	0.0025	0.817
Productive tillers	y = 0.3421x + 4.5726	0.304959	0.093	0.147
Days to maturity	y = 0.0581x + 0.0936	0.595483	0.3546	0.002

Chulsa yields (5.65 t/ha) in the current study were above the Cambodian national wet season average of 3 t/ha and Chulsa seeds are readily available at a lower cost of US$80 compared with hybrid seeds at a cost of US$267 for Arize TEJ and US$281 for TH3-3 for 100 kg of seed (Cai *et al.* 2008). Current rice prices of US$250-375/t for paddy rice compounded with the high cost of fertilisers of up to US$600/t may make it

economically unfeasible for farmers to invest in hybrid seeds when they can only achieve an output yield of 7 t/ha. Although hybrid seeds could be planted at a lower sowing rate of 30-40 kg/ha compared with 80-100 kg/ha for local seeds, resulting in a similar cost to local seeds, hybrid seeds are not readily available in Cambodia. When available there are concerns about the purity of imported hybrid seeds. As only one year (2014) of data is presented, this experiment will be repeated in 2015.

Conclusions

This study suggests that hybrids can produce high yields when grown in Cambodia. PAC 837, Arize TEJ and Arize BTE-1 yielded 15-20% higher than other varieties including the local open pollinated cultivar, Chulsa. Short duration hybrid cultivars such as TH3-3 and HBO-2 can be suitable for areas prone to late season flooding. Hybrids can be a means of increasing rice production but they are not the only available option.

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On-row seeding as a tool for management of water repellent sands

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Abstract
Water repellent (non-wetting) sands are prevalent in many crop-producing regions of southern Australia, and pose challenges for crop production in terms of crop establishment, nutrition, and weed control. In this research we investigate the tactic of on-row seeding, compared with inter-row seeding, over two successive years (2012-13) on a trial near Calingiri, Western Australia. During August in both years, plots established using on-row seeding were less-severely repellent, with MED values in the crop rows of 2.8 and 2.9 in 2012 and 2013 respectively, compared with MED values in the crop rows of inter-row sown plots of 3.3 and 3.3. In 2012, crop emergence was significantly greater (147 vs 79 plants per square metre) in the on-row sown treatment, but there was no significant difference in 2013 (86 vs 80 plants per square metre). There was no significant difference in crop yield in 2012, with an average wheat yield of 2.1 t/ha, but in 2013, inter-row sown barley yielded 3.2 t/ha compared with on-row sown barley 2.9 t/ha ($p = 0.03$). Yields in both treatments in 2013 were affected substantially by ryegrass. Despite the lack of positive yield response, changes in MED values and crop emergence suggest that on-row seeding may be a viable tool for long-term management of crop production in water repellent soils.

Key words
Water repellency, crop row placement, germination

Introduction
Soil water repellency is cited by many farmers in south-western Australia as one of their main soil constraints to crop production (Davies et al., 2013). Water repellent soils are also prevalent in parts of South Australia and Victoria, and have been estimated to affect more than 10 M ha of sandy soils across southern Australia (Roper et al., in press). Rainfall infiltration into water repellent soils is characteristically patchy, resulting in patchy and staggered crop germination, and also staggered germination of weeds.

Some farmers on the south coast of Western Australia manage water repellency by maintaining full residue retention combined with minimal soil disturbance (Hall, 2009; Roper et al., 2013). In this system, the severity of water repellency is actually increased (Roper et al., 2013), but higher soil water contents, and better crop yields, are observed than when these systems are perturbed by residue removal or soil tillage. Roper et al. (2013) attributed this to the maintenance of preferred pathways of water entry into the soil, often along the old intact crop root systems, as also speculatively proposed by Blackwell (2000).

This suggests that crops sown immediately alongside the old crop rows may have better access to soil water, and may perform better, than crops sown in between the old crop rows. Farmer observations have supported this hypothesis (Steve Waters, personal communication; Figure 1), and have even led to development of machinery specifically designed to allow close on-row seeding (e.g. the iTill system; Paul Hicks, personal communication; see also www.itill.com). In this research we investigate crop emergence and yield, and soil water repellency, for crops grown on the old crop row, compared with crops sown in the inter-row space.

Figure 1. Canola sown on a water repellent soil on the old crop row on the left, and on the old inter-row on the right, in a farmer (Steve Waters) paddock at Calingiri, Western Australia.

Materials and Methods

Site details

A site was chosen on a water repellent sandy gravel at 31° 8' 15.6"S, 116° 20' 42.0"E, near Calingiri, 150 km north-east of Perth, WA. Average annual rainfall at Calingiri is 422 mm, of which 323 mm falls in the May to October period.

Plots were established in a randomised block design with 4 replicates, including treatments of crops sown on the previous year's stubble rows, compared with crops sown in the inter-row spaces of the previous year's stubble. Plots were established in April 2012, and were 12 m long by 8.9 m (one seeder width) wide, with a row spacing of 0.18 m. Wheat was sown in May 2012, and barley was sown in June 2013, using a knife point seeder with trailing press wheels. Statistical analysis was performed by analysis of variance, and results were considered significant at the 5% level.

Crop measurements

In both 2012 and 2013, crop emergence was assessed approximately three weeks after sowing. Seedlings were counted in two adjacent crop rows over a 1.0 m length, in nine locations, giving a total of 18 m of row length measured in each plot.

Crop yield was measured by harvesting three strips of 1.76 m wide (the plot header width) by 9.0 m long in each plot.

Water repellency measurement

Soil samples were collected from the crop rows during August of both years from a depth of 0.0 to 0.05 m. Samples were dried at 105°C, returned to 20°C, and sieved to less than 2.0 mm to remove large organic matter and gravel. Water repellency was measured using the Molarity of Ethanol Droplet (MED) test (King 1981), where a value of 0 indicates a wettable soil, and greater than 3.0 indicates severely water repellent.

Results

Crop emergence and yield

In 2012, wheat emergence was significantly ($p < 0.001$) greater when sown on the stubble row, compared with being sown in the inter-row (Figure 2). In 2013, there was no significant difference in barley emergence. Crop yield was not affected by row position in 2012 (Figure 3), but in 2013, barley sown in the inter-row position yielded significantly ($p = 0.013$) more than crops sown on the old stubble row.

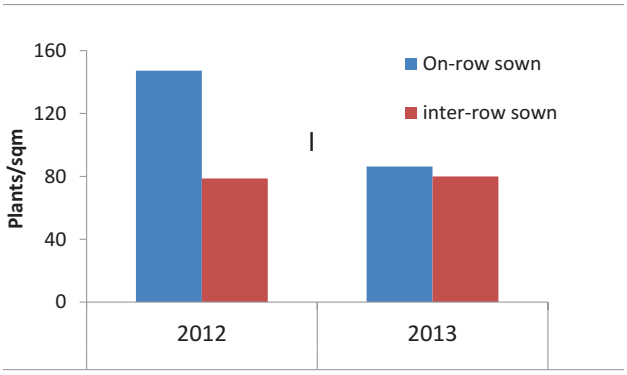

Figure 2. Emergence counts for wheat (2012) and barley (2013) sown either on the old crop row, or in the inter-row position. Vertical bar represents the LSD value.

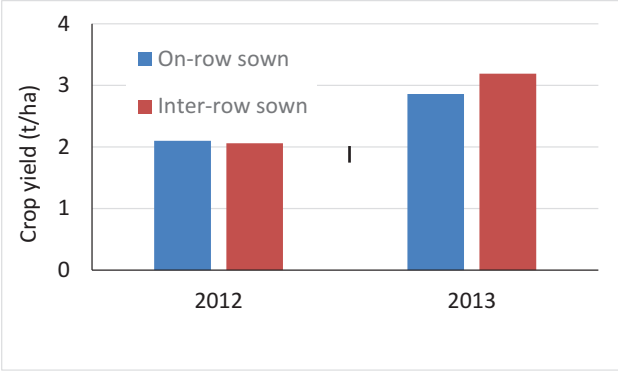

Figure 3. Crop yield (t/ha) for wheat (2012) and barley (2013) sown either on the old crop row, or in the inter-row position. Vertical bar represents LSD value.

Soil water repellency

Soil water repellency in the crop rows, as measured by the MED test, was significantly (p= 0.042) less severe where crops were sown on the old row, than where crops were sown in the inter-row spaces (Figure 4), in both 2012 and 2013.

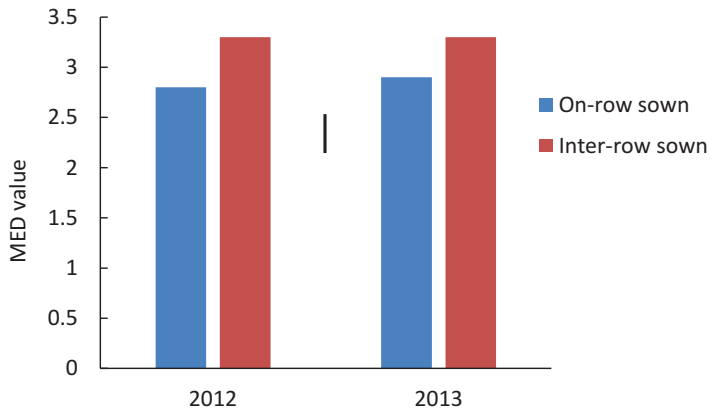

Figure 4. Soil water repellence in the crop rows for crops sown either on the old crop row, or between the old crop rows. Vertical bar represents LSD value.

Discussion

The symptoms of water repellency (patchy and staggered crop germination) depend on the temporal patterns of rainfall at the break of the season, and so the expression of water repellency varies considerably from year to year. In our results, a substantial impact on crop emergence was observed in 2012, but not in 2013. Furthermore, in both years, seasonal conditions during later crop growth and grain filling were sufficiently mild to ensure that crops sown on the old crop row did not show a yield advantage. Indeed, in 2013, crops sown on the old crop row actually yielded less than crops sown in between the old rows, but in 2013, yields were influenced by a large ryegrass population, and so may not be representative of potential yields. Improvements in establishment in response to on-row seeding were also observed by Davies et al. (2012), but crop yields were not reported in this study. Therefore, although anecdotal evidence of improved yields with on-row seeding is compelling (Steve Waters, personal communication; Paul Hicks, personal communication), there is still no experimental evidence (of which we are aware) that confirms this.

Our results also demonstrate that soil in the crop rows shows lower levels of water repellency (as measured by the MED test) when crop rows are established on or close to previous crop rows, compared with crop rows established in the inter-row spaces. Where crops are grown on the previous crop row, there is likely to be greater organic matter and nutrient accumulation, which could encourage microbial activity. Furthermore, as shown by improved crop establishment, soil water is also likely to be more favourable for crop growth and microbial activity in on-row sown crops. As shown by Ward et al. (2013) and Roper et al. (2013), soil water contents in water repellent sand were greater in crop rows than in the inter-row spaces, and where residue

was retained. We speculate that improvements in soil water availability, and increases in organic matter, both associated with on-row seeding, might encourage microbial activity, leading to increased degradation of the compounds causing water repellency.

Water repellency causes significant losses in crop production, and management strategies vary from cheap (residue retention with no-till, minor changes to seeding boots, wetting agents) to expensive (clay addition, rotary spading, soil inversion). The most profitable management options will depend on the scale of water repellency on any farm (Blackwell et al., 2014). With the wide availability of 2 cm autosteer, on-row seeding may become an additional relatively low cost option for management of water repellency for crop production.

Conclusions

On-row seeding, compared with inter-row seeding, was shown to increase crop establishment in one season, but not in another. There was no positive impact on crop yield. However, improvements in establishment, combined with observations suggesting decreased severity of water repellence in crop rows sown on the old crop row, suggest that on-row seeding may be a useful and low-cost option for management of water repellent soils for crop production. The implications of long-term use of on-row seeding on soil nutrition, organic matter, soil structure and soil-borne diseases on water repellent soils needs further research.

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Defining optimum plant population and row configuration for sunflower in northern NSW

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Abstract
Sunflower (*Helianthus annuus*) production in Northern NSW is highly variable depending on commodity price, seasonal climatic conditions and grower confidence in crop performance. The major production regions are the Liverpool Plains and Moree in North West NSW. Commodity price and climatic conditions are beyond control; however other factors can be influenced. Development of an agronomic package to improve the reliability of crop performance, both yield and oil content is an important way of improving grower confidence. Four experiments were conducted in 2004-5 and 2005-6 focused on determining dryland plant populations, with treatments of 15, 25, 35, 45 and 55,000 plants/ha. No significant difference in yield was determined. Target plant populations of 25-35,000 plants/ha for the Liverpool Plains and 20-25,000 plants/ha for Moree were suggested as optimal at the time. In 2007-8 two experiments at Quirindi, Liverpool Plains and Moree tested row configurations of 75 cm solid, 75 cm single skip, 150 cm super wide, 100 cm solid and 100 cm single skip across three plant populations of 27, 37 and 46,000 plants/ha. At Quirindi, yields from the 75 cm solid, 100 cm solid and 75 cm single skip were comparable. At Moree the slightly wider 100 cm solid, 100 cm single skip and 75 cm single skip were comparable. In 2014-15, one trial was established at Pine Ridge to examine the interactions of population, row configuration and hybrid. Three plant populations; 25, 35 and 45,000 plants/ha; three row configurations of 75 and 100 cm solid plant and 150 cm super wide and three sunflower hybrids were used. No interactions were evident between the three factors, however the highest yields were obtained from the 35 and 45,000 populations and the 75 cm solid plant.

Key words
row spacing, plant density, Liverpool Plains, Moree

Introduction

Sunflower (*Helianthus annuus*) production in northern NSW is highly variable, but on average 30,000 ha is sown each season. The area sown reached a low point in 2002-3 of 8,920 ha followed soon after by a high in 2005-6 of 79,200 ha (Scott 2012). The two major regions of sunflower production in northern NSW are on the Liverpool Plains; stretching south from Gunnedah to Willow Tree; and Moree; typically east of the Newell Highway.

Two of the most important agronomic decisions made by growers and advisors prior to planting their sunflower crops relate to the optimum plant population to be established and the ideal row configuration for their region. In the Moree region there is a stronger focus on reducing the risk of crop failure and improving reliability, while the focus on the Liverpool Plains is on maximising yield. These different approaches are largely a reflection of each regions inherent climatic difference as Moree receives less rainfall and higher temperatures than the Liverpool Plains.

Over the last ten years a range of trials have been conducted, initially in 2004-2006 targeted at identifying the ideal dryland plant population in each region, however in 2007-8 the trials were expanded to include row configuration as another key management decision. In 2014-15 it was decided to begin development of one robust data set to examine the interactions between plant population, row configuration and hybrids.

Current recommendations for sunflower in the Moree region are to target established plant populations of 20-25,000 plants/ha using a 100 cm solid plant or single skip configuration and for the Liverpool Plains to sow on a 75 cm solid plant aiming to establish 25-35,000 plants/ha (Moore 2014).

Methods

2004-5 and 2005-6 seasons

In the 2004-5 season trials were planted at Pine Ridge and Tamarang on the Liverpool Plains. The Pine Ridge trial was sown in the early planting window (September) and the Tamarang trial in the late planting window (Dec- Jan). In the 2005-6 season two early plant trials were conducted, one at Mallawa, west of Moree and the second at Pine Ridge on the Liverpool Plains. All of the trials were sown using the monounsaturated hybrid Ausigold 61.

The trials were planted using a cone seeder on 91cm plant spacing. A series of five target plant populations were included in each trial, 15, 25, 35, 45 and 55,000 plants/ha. The target plant populations were achieved through hand thinning early post emergence. Each trial consisted of five treatments with three replications in a fully factorial design. Plots consisted of four rows of plants, each plot being 18 m in length and 3.6 m in width. All of the plots within each trial were harvested using a K.E.W plot header. Grain yields and oil contents were measured for each plot.

2007-8 season

In the 2007-8 season trials were planted in two locations, Quirindi on the Liverpool Plains and Biniguy, east of Moree. The trials were planted using a Monosem precision planter and were partially factorial. In the trial at Quirindi, three plant populations of 27, 37 and 46,500 plants/ha were targeted on a 75 cm solid configuration. In addition five row configurations of 75 cm solid, 100 cm solid, 75 cm single skip, 100 cm single skip, 150 cm super wide were also included. In the Biniguy trial, four row configurations of 75 cm solid, 100 cm solid, 75 cm single skip and 100 cm single skip were included. Two replicates were included of each treatment. Plots were 100m long and 8 rows wide. The centre two rows of each treatment plot in both trials were harvested using a K.E.W plot header. Grain yields and oil contents were measured for each plot.

2014-15 season

One early sowing data trial was planted in 2014-15 at Pine Ridge on the Liverpool Plains. The trial was sown using a Monosem precision planter. The trial at Pine Ridge was fully factorial designed to investigate interactions between three row configurations of 75 cm solid plant, 100 cm solid plant and a 150 cm super wide, three target plant populations of 25, 35 and 45,000 plants/ha and three hybrids; Hyoleic 41, Ausigold 62 and an experimental line. The plots were 10m long and 4 plant rows wide. There were three replicates of each treatment with the centre two rows of each plot harvested using a K.E.W plot header to measure grain yield. Oil contents were not available at the time of publication.

Results

2004-5 and 2005-6 seasons

In 2004-5 and 2005-6 seasons there was no significant difference in yield for any of the five plant populations included in the four trials. Yield in the Liverpool Plains trials, at both Pine Ridge and Tamarang were on average 2.6 and 2.1 t/ha respectively (Table 1). Both yields are considerably higher than the long term average for the Liverpool Plains of 1.5 t/ha. At the Pine Ridge site, oil contents were highest at the 25,000 plant population. Oil contents were well above the receival standard of 40% for all populations.

Table 1. Effect of plant population on yield and oil content on the Liverpool Plains 2004-5

Plant population (/ha)	Yield (t/ha)		Oil Content %	
	Pine Ridge	Tamarang	Pine Ridge	Tamarang
15,000	2.53	2.18	42.4 [b]	43.59
25,000	2.63	2.24	45.1 [a]	43.85
35,000	2.70	2.14	43.6 [b]	43.50
45,000	2.57	2.09	43.0 [b]	43.40
55,000	2.57	1.84	43.7 [b]	44.31
Lsd	n.s.	n.s.	1.35%	n.s.

In the 2005-6 trials average yields were 1.90 t/ha at Mallawa, west of Moree and 1.65 t/ha at Pine Ridge (Table 2). There was no significant impact of varying plant population or oil contents in either of these trials.

Table 2. Effect of plant population on yield and oil content at Mallawa, Moree West and Pine Ridge, Liverpool Plains in 2005-6

Plant population (/ha)	Yield (t/ha)		Oil Content (%)	
	Mallawa, Moree	Pine Ridge	Mallawa, Moree	Pine Ridge
15,000	1.80	1.82	41.49	37.13
25,000	1.99	1.71	39.08	40.13
35,000	1.92	1.73	41.20	40.60
45,000	1.91	1.44	41.02	40.13
55,000	1.87	1.54	41.93	38.01
Lsd	n.s.d	n.s.d	n.s.d	n.s.d

Source: Belfield, Ferguson and Serafin. Personal communication.

2007-8 season

There was no significant difference in the grain yield or oil content from varying plant population in the 75 cm solid plant treatment at Quirindi where average yields of 2.2 t/ha and oil contents of 40.41% (Table 3).

Table 3. Effect of plant population on yield and oil content at Quirindi 2007/8

Plant population (/ha)	Row Spacing (75 cm)	
	Yield (t/ha)	Oil Content %
27,000	2.25	39.69
37,000	2.24	40.03
46,500	2.04	40.41
Lsd	n.s.	n.s.

Varying row configuration resulted in differences. The highest yields were obtained from the 75 cm solid plant or single skip treatments and the 100 cm solid plant. The super wide (150 cm) and 100 cm single skip treatments yielded significantly less (Table 4). There was no significant difference in the oil contents at the 75cm row spacing. Oil contents were significantly reduced in the 100 cm single skip treatment compared to the 100 cm solid plant.

Table 4. Effect of row spacing on yield and oil content at Quirindi 2007/8

	75 cm Row Spacing		100 cm Row Spacing	
	Yield (t/ha)	Oil Content %	Yield (t/ha)	Oil Content %
Solid Plant	2.39 [a]	41.29	2.19 [a]	39.49 [a]
Single Skip	2.15 [a]	39.79	1.51 [b]	37.78 [b]
Superwide Row (150 cm)	1.99 [b]	39.05	-	-
Lsd	0.26	n.s.d	0.20	1.13

In a lower yielding environment at Moree, there was a significant impact of varying row configuration on yield and oil content (Table 5). The 75 cm solid plant treatment yielded less than the other four configurations. There was no significant difference between the solid or single skip 100 cm configuration or the 75 cm single skip. The 100 cm single skip treatment produced lower oil content but was still above the 40 % receival standard.

Table 5. Effect of row configuration on yield and oil content at Moree 2007/8

Row spacing (cm)	Yield (t/ha)	Oil Content (%)
Solid – 100	1.19[a]	43.92 [a]
Single skip – 100	1.14[a]	42.40 [b]
Single skip – 75	1.11[a]	44.02 [a]
Solid – 75	0.78[b]	43.73 [a]
Lsd	0.15	1.01

Source: Belfield and Serafin, Personal Communication 2010

2014-15 season

The 2014-15 trial at Pine Ridge produced significant differences for yield with the lowest population; 25,000 plants/ha being lower yielding than the other treatments (Table 6). There was no difference in yield with the

35 and 45,000 plant/ha treatments.

Table 6. Effect of varying plant population on yield at Pine Ridge 2014/15

Plant population (/ha)	Yield (t/ha)
25,000	2.32_b
35,000	2.88_a
45,000	2.84_a
Lsd	0.16

The narrowest row spacing, 75 cm solid plant produced the highest yield, whereas there was no difference in the yield from the 100 cm solid or super wide treatments (Table 7). While the trial included a fully factorial design to evaluate any interactions between hybrid, plant population and row configuration no interactions were significant.

Table 7. Effect of row configuration on yield at Pine Ridge 2014/15

Row configuration (cm)	Yield (t/ha)
Solid – 75	2.99_a
Solid – 100	2.66_b
Super wide – 150	2.42_b
Lsd	0.27

Conclusion

A series of four trials in the 2004-6 seasons showed no response to varying plant population between the range of 15 – 55,000 plants/ha at sites where average yields were above the long term regional average. A response in oil content was only detected at one site, where the plant population of 25,000 plants/ha produced the highest oil content. Anecdotal results at that time, from these two regions, Moree and the Liverpool Plains suggested plant populations of 20-25,000 and 25-35,000 plants/ha respectively for each region.

Results from trials in the 2007-8 season in both regions generated further preliminary recommendations. On the Liverpool Plains it was suggested to sow on a 75 cm solid plant, 75 cm single skip or a 100 cm solid plant to achieve higher yields. Again no significant differences from varying plant populations were identified. In contrast at Moree slightly wider row configurations of 100 cm solid plant, 100 cm single skip or a 75 cm single skip produced the highest yields.

The 2014-15 trial at Pine Ridge produced a significant response to varying plant population. The 35 or 45,000 plants/ha treatments produced the highest yields as did the 75 cm solid plant configuration. The lack of significant response to varying plant population at six of the seven trials most likely demonstrates the compensatory mechanisms of sunflower, that is altering head diameter, head arc length and plant height.

Based on the data presented in this paper, there is no reason to alter current plant population recommendations of 20-25,000 plants/ha for Moree and 25-35,000 plants/ha for the Liverpool Plains. Higher plant populations require additional seed costs for no additional return from grain yield and it is difficult to achieve uniformity with lower populations of around 15,000 plants/ha. Similarly the row configuration recommendations of 75 cm solid plant for the Liverpool Plains and 100 cm solid plant or single skip for Moree remain. Both of these confirm the most common current commercial practice of sunflower growers in these regions. Additional trials are planned for both regions to continue to investigate any interactions between plant population, row configuration and hybrid selection.

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Impact of Seeding Density and Time of Sowing on Soybean Productivity in Southern NSW

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Abstract
With the expansion of the irrigated soybean industry in southern NSW and the release of new high yielding varieties there has been a gap identified in the knowledge of specific variety agronomy required for maximizing grain yields of these varieties. Preliminary trials by NSW Department of Primary Industries at Yanco have shown significant yield increases can be made with only small changes to plant populations and time of sowing. Grain yield results from these trials grown under a furrow irrigated raised bed (2 rows/bed) system indicate there are positive yield responses with plant densities up to 35 plants/m^2.

Key words
Density, maturity, lodging, plant population, yield.

Introduction
The irrigated soybean industry in southern NSW plays an important role as a legume crop in a diverse multi seasonal irrigated cropping system. While soybean agronomy is more complex than that of cereals, it can be very responsive to good management (James et. al. 1996). With the increasing cost of inputs, in particular water and its allocation availability, it is important that growers maximise returns per mega litre (ML) of water. If variety specific soybean agronomy guidelines were developed which are easily implemented, growers could reduce input costs, and stabilise yields. By managing seeding densities, time of sowing and variety selection growers could reduce seeding costs, increase harvest index and increase harvesting efficiency through reduced crop lodging.

Current breeding objectives for the southern region in the Australian Soybean Breeding Program (GRDC CSP00157) are to produce soybean varieties suitable for human food markets that are high yielding, early maturing, with disease tolerances and good agronomic traits. Ideally, in southern NSW later sowings and earlier maturity offer greater flexibility for fitting soybean into double-cropping systems (Gaynor et.al. b. 2011).

In this paper we look at some agronomy management options such as time of sowing and plant density treatments to improve yields of current varieties, namely Bidgee, Snowy and Djakal. A potential new variety NOO5A-80 was also included in the experiments. To enable growers to maximise yield, some variety specific agronomy practices need to be evaluated and identified.

A gap in knowledge for maximising the yield of the variety Bidgee, released in 2012 has been identified. This is due to the significant phenology differences between Bidgee and other varieties currently grown, Djakal and Snowy. Bidgee differs greatly with a significantly shorter time to physiological maturity, smaller seed size, shorter plant height and apparent photoperiod and thermal growth response. In order to maximise yields it is also important to understand the differing variety responses across seasons with different management practices.

Materials and methods
The following trials were conducted on the NSW Department of Primary Industries Leeton Field Station. The trials were grown on a self-mulching medium clay soil, on 1.83m wide beds, with 2 rows per bed, at 90 cm row spacing. The beds were in-furrow irrigated with approximately 8 ML/ha of applied water for the entire growing season. All plots were in-furrow inoculated and all plots were sown with 125 kg/ha of grain legume fertiliser at sowing.

Plant populations x time of sowing trial 2012/13
A trial was conducted to test the yield response of the current varieties Bidgee, Snowy and an advanced breeding line NOO5A-80 at target densities of 10, 20, 30 and 40 plants per m^2. Seeding rate calculations were based on actual seed weight with measured germination and a plant establishment of 85%. The trial was repeated at 2 sowing times in the recommended sowing window for southern NSW, with the first sown on 22 November 2012 and the second on 21 December 2012. These sowing times are considered ideal for the November sowing time and late, but acceptable, for the December sowing time.

Plant population trial 2013/14
A further plant population trial was conducted at the Leeton Field station in 2013/14 station to test the yield response of 4 varieties Bidgee, Djakal, Snowy and NOO5A-80 over five plant densities from 10 to 50 plants per m^2. The trial was sown 21 November 2013.

Results
Plant populations x time of sowing trial 2012/13
Yield and lodging results from this trial indicate that the varieties tested respond differently to increases in plant density and time of sowing. The population data is presented as seeding densities because actual plant density data was not available. However, the plant populations targeted were observed to be reliable.

The first sowing date had a trial mean yield of 3.9 t/ha, an increase of 0.7 t/ha or 18% over the second time of sowing, with a trial mean yield of 3.2 t/ha. Within each variety there was some differences detected. Snowy showed significant yield responses across all densities while NOO5A-80 showed significant ($p<0.05$) yield increase at the 20, 30 and 40 plants/m^2 treatments. Bidgee showed no significant yield increase across all density treatments in time of sowing 1 (Figure 1). The yield difference between time of sowing 1 and 2 indicates that for a yield level of <3 t/ha, a population of 10 to 20 plants/m^2 is adequate from this data. To achieve grain yields >3 t/ha, plant densities from 20 to 30 plants/m^2 would be required.

Interestingly, increasing the sowing density with delayed sowing did not generally increase grain yield. A possible reason for this could be due to the delay in crop maturity with the cooling temperatures of autumn. The growth rates of soybeans are reduced with cool temperatures and this may combine with their in-determinant nature to limit yield potential. Further study is required to look at plant seed yield distribution at each node site and the plants pod and seed development late in the season under cool temperatures. This trial indicated that Bidgee had a relatively stable yield across the population range possibly due to its quick growth rates and phenology compared to Djakal and NOO5A-80. It is important to consider that this time of sowing affect is only measured over one season and further analysis over multiple seasons is required to identify some definitive genotype and environment interactions.

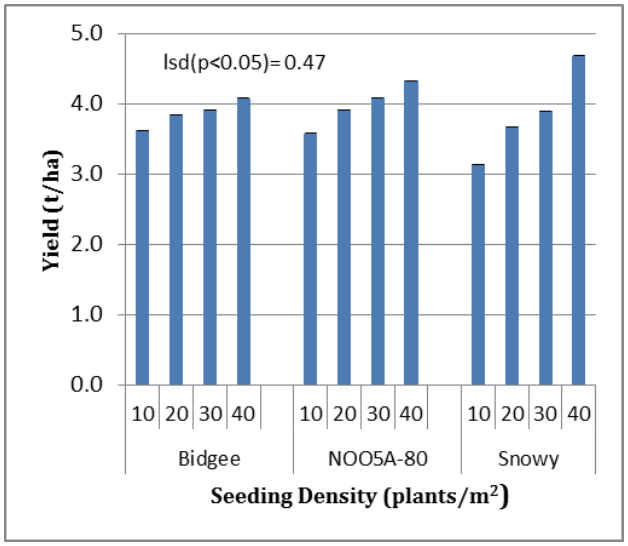

Figure 1. Effect of seeding density on 3 varieties x 4 sowing densities. Sown at Leeton Field Station on 22 November 2012.

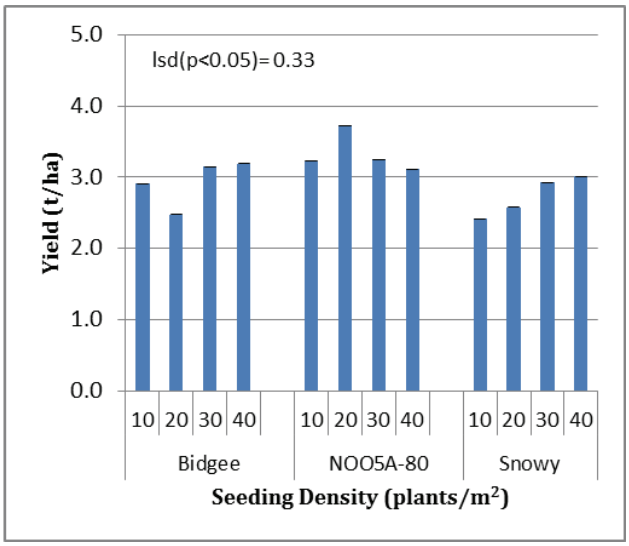

Figure 2. Effect of seeding density on 3 varieties x 4 densities. Sown at Leeton Field Station on 21 December 2012.

There were significant ($p<0.05$) differences measured in varieties, from the number of days to 95 % of plants reaching physiological maturity (P95) between sowing time 1 and 2. Due to an apparent thermal response Bidgee and Snowy had large reductions in their days to P95 of 16 and 11 days respectively. The delayed sowing had a lesser effect on Djakal and NOO5A-80 of 4 and 5 days. Under the same environment and seasonal conditions, the length of the growing period of Bidgee and Snowy appear to be strongly affected by thermal time and photoperiod than that of Djakal and NOO5A-80. Djakal and NOO5A-80 have a more stable length of growing season and are less affected by changes in time of sowing and seasonal conditions. The length of the growing season of Djakal & NOO5A-80 appears to be relatively stable irrespective of date of sowing. Bidgee and Snowy tend to mature at similar times irrespective of time of sowing. This characteristic leads to less biomass and a lower yield potential.

Plant population trial 2013/14

Five plant populations were sown within each variety and plant populations were measured for each treatment and can be seen below in Table 1. Some significant yield and lodging interactions were observed in this trial. Averaged across all varieties, the Treatment 1 was 0.85 t/ha (24%) lower yielding than the average yield of treatments 2 to 5. There was no significant ($p<0.05$) yield difference between sowing density treatments 2-5 averaged across all varieties (Figure 3).

Table 1. Seeding Densities. Trial sown at Leeton Field Station on 21 November 2013.

	Seeding Density (plants/m^2)				
Variety	**Treatment 1**	**Treatment 2**	**Treatment 3**	**Treatment 4**	**Treatment 5**
Bidgee	8	21	25	33	49
Djakal	6	13	21	29	32
NOOSA-80	8	19	26	37	43
Snowy	8	23	30	36	44
Mean	**8**	**19**	**25**	**34**	**42**

Snowy scored significantly higher than all other varieties for plant lodging across all densities (Figure 4). Snowy has a known strong genetic link to plant lodging which could explain the majority of differences observed in this experiment. Data from previous work indicates the degree of lodging with Snowy varies depending on season and rainfall. It has been observed that high rainfall at peak total dry matter can contribute to severe lodging. There was also a significant ($p<0.05$) increase in lodging with all increases in sowing populations.

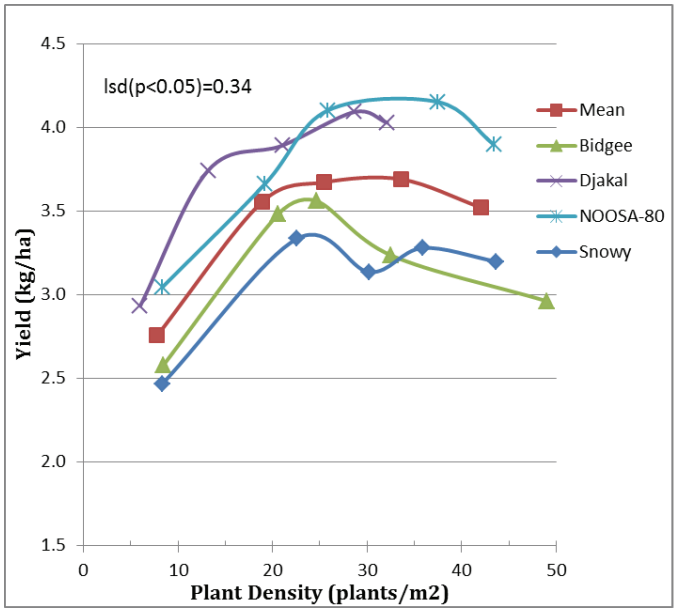

Figure 3. Grain yield of 4 varieties at 5 densities. Trial sown at Leeton Field Station on 21 November 2013.

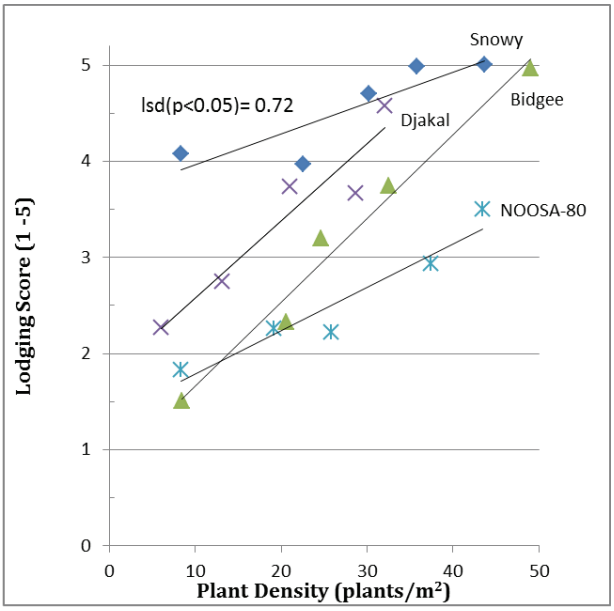

Figure 4. Variety lodging score (1 = erect, 5 = flat) of 4 varieties at 5 target plant densities. Trial sown at Leeton Field Station on 21 November 2013.

While all varieties recorded a significant difference in seed size across varieties there was also a significant reduction in seed size across varieties at the lowest population Treatment 1 of 4% (data not presented). This reduction in seed size may have contributed to the yield decrease of this treatment. No significant effect of population on seed protein level was observed.

There was a significant effect of population on crop duration from sowing to 95% physiological maturity (P95). There was an average increase of 3.5 days for densities greater than 35 plants/m^2. This is likely to be due to the delay in maturity caused by increased biomass and lodging and hence the longer time to reach physiological maturity under an irrigated system. Frequent observations from previous trials have shown this affect. The main consequence of this is that harvest maturity will be delayed, as a result of the plant and seed take longer to dry down.

Discussion

Grain yield results from these trials grown under a furrow irrigated raised bed (2 rows/bed) system indicate that increasing soybean sowing rates above 35 plants/m^2 show no yield advantage. It will not only result in a lower gross margin due to increased seed costs, but also increased harvest difficulties as a result of significant increases in plant lodging.

It would appear from these trials that in southern NSW a target plant density of 35 plants/m^2 is adequate for maximising yields whilst minimising the risks of increased lodging from higher sowing rates above this level. Whilst Snowy shows increases in grain yield with increases in population, there are some considerable disadvantages, including increased lodging, delayed harvest and decreased harvest efficiency. Plant breeding programs should continue to invest in developing lodging resistant cultivars.

The genotype NOO5A-80 performed strongly in these experiments and shows great promise with good yields, a stable growing season length and lower lodging potential.

It would appear from this preliminary work that current varieties respond differently from delayed sowing to days to physiological maturity (P95). Bidgee in particular with its characteristic quick maturity exhibits a likely temperature related physiological response which reduces the total days of crop duration in a delayed sowing situation. This response could reduce the total amount of biomass produced and therefore reduce the total yield potential of the crop. Further research is required to identify the effects of this genotype by environment response so as to make more specific agronomy guidelines to maximise yields with current varieties.

Further research is currently underway in the GRDC project (DAN00192) Southern NSW Soybean Agronomy to investigate strategies required to maximise the grain yields of new and existing soybean varieties in southern NSW and northern Victoria.

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Effect of 1 m and 1.5 m row spacing on yield and fibre quality of upland cotton (*Gossypium hirsutum*) in Warren, NSW, Australia

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Compaction by machinery traffic increases soil strength and reduces soil porosity, which hinders root growth, moisture and nutrient uptake. GPS-auto steer and modification of machines to 3 m wheel centres can minimise field compaction. Conventional 1 m cotton does not accommodate 3 m wheel centres, so row spacing can be altered to alleviate this issue. The aim of this study was to test the hypothesis: is cotton yield and fibre quality in wide 1.5 m row the same as conventional 1 m rows? There were two experiments at Auscott Warren farm; a randomised block design field experiment with nine replicates of 1 m and 1.5 m row treatment and a paddock scale experiment which was two large field blocks of 1 m and 1.5 m row treatments. 1.5 m cotton was 10 cm taller than 1 m cotton. The 1 m cotton yielded 1.8 bales/ha and 3.6 bales/ha higher than the 1.5 m cotton in the machine picked and handpicked replicated experiment, respectively. Yield of 1 m cotton mainly came from fruiting nodes 1-8, position 1, whereas yield in 1.5 m cotton mainly came from vegetative branches. There was a strong positive correlation ($R^2 = 0.99$) between the number of bolls/m2 and yield. In the 1.5 m cotton there were minor improvements in fibre quality compared with the 1 m cotton. Gross margins of the two row configurations were very similar. Reduced water use of 1.5 m cotton allows for more hectares to be grown and potentially a more profitable farming system. Future research should quantify water use to improve grower decision making.

Key words
Controlled traffic, Gossypium hirsutum, irrigation, row configuration, wide row

Introduction

Row spacing can play a large role in performance of dryland and irrigated crops. In dryland situations wide row spacing and skipped rows can be used as a management technique to minimise production risk in dry years but compared with closer row spacing can limit top end yields in favourable conditions (Whish *et al*. 2005). Narrow row spacing increases yield in more favourable rainfed environments and in irrigated environments by increasing crop leaf area and associated light interception (Brodrick *et al*. 2010). The vast majority of irrigated cotton in Australia is grown in solid configuration, on 1 m row spacing. The traditional row spacing in Australia of 1 m does not accommodate 3 m wheel centres and a controlled traffic system at Auscott Warren. Altered row spacing including wide row (1.5 m) or narrow row (0.75 m) cotton can facilitate a controlled traffic system on 3 m wheel centres. There has been a considerable research into Ultra Narrow Row (<0.4 m), narrow row (0.75 m) (Brodrick *et al*. 2010) and 1 m cotton, but little is known about the performance of irrigated wide row (1.5 m) cotton. This study will investigate the hypothesis: is cotton yield and fibre quality in wide 1.5 m row the same as conventional 1 m rows? The aim of the study is to compare the yield and fibre quality of wide row (1.5 m) and conventional (1 m) cotton grown under irrigated conditions.

Materials and methods

There were two main components of this study at Auscott Warren farm (31°47'25" S 147°44'17" E, 195 m above sea level), a replicated plot experiment and a paddock scale whole block experiment. Auscott Warren is located 11 km south west of Warren in the central west area of NSW, Australia. The area is considered semi–arid, receiving an average rainfall of 490 mm per annum, which is evenly split between summer and winter, of which 236 mm fall on average during the cotton growing season (October – February). Hot summers (mean daily maximum 33.4°C, and minimum 19°C) and mild winters (mean daily maximum 15.6°C and minimum 3.4°C) are typical of the area. Self-mulching grey Vertosols dominate the irrigated areas of the farm.

The replicated plot experiment was a randomised block experimental design with 9 replicates. All experiments used the variety Sicot 74BRF (Bollgard II™ Roundup Ready Flex™). At harvest maturity, just prior to defoliation, plant height and harvest index (ratio of fruit to vegetative dry biomass) were measured.

The cotton from each linear metre was handpicked and grouped into different fruiting segments of the plant. Fibre quality parameters were measured using the High Volume Instrument (HVI).

The paddock scale experiment was conducted on a large 17.5 ha block that was divided into two whole blocks of 8.75 ha each for the 1 m, and the 1.5 m row configuration treatments, which were separately machine harvested. The harvested seed cotton from each block was ginned separately to provide an infield broad scale comparison between 1 m and 1.5 m row spacing. Both the handpicked and machine picked yields were recorded in bales/brown ha and bales/green ha (227 kg lint bales). The term brown ha refers to the total area taken to grow the wide row crop in hectares, whereas the term green ha refers only to the area covered by plant rows and does not account for the additional space between the rows. Brown hectares are generally used in the Australian cotton industry as it represents the actual area required to grow the crop. Data were analysed using analysis of variance (ANOVA) and regression in Genstat v16.

Results and discussion

Cotton yield

Final heights were 92 cm for 1 m and 102 cm for 1.5 m cotton. This is consistent with other work where Ultra Narrow Row cotton (< 0.4 m) plants were considerably shorter and smaller compared with 1 m rows (Brodrick et al. 2010). In the machine picked fields, the 1 m cotton out yielded the 1.5 m cotton by nearly 2 bales/ha, a 16% yield difference (227 kg lint per bale) (Fig. 1). A similar trend emerged with the handpicked data where the 1 m cotton out yielded 1.5 m by 3.6 bales/ha (23%). In the segment picked cotton, yield on the 1 m row spacing was confined to mainly first position fruit on fruiting nodes 1-8, and some vegetative fruit (Fig. 2a). In contrast yield on the 1.5 m spacing was mainly derived from vegetative branches, along with a smaller contribution from fruiting nodes 1-8 (Fig. 2b).

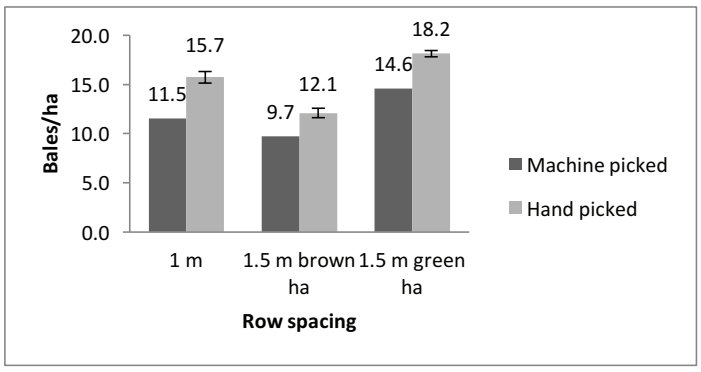

Figure 1. Cotton lint yields harvested (227 kg bales) by machine and by hand from cotton grown on 1 m and 1.5 m row spacing. The term brown ha refers to the total area taken to grow the wide row crop in ha, whereas the term green ha refers only to the area covered by plant rows. Error bars represent standard errors of the mean.

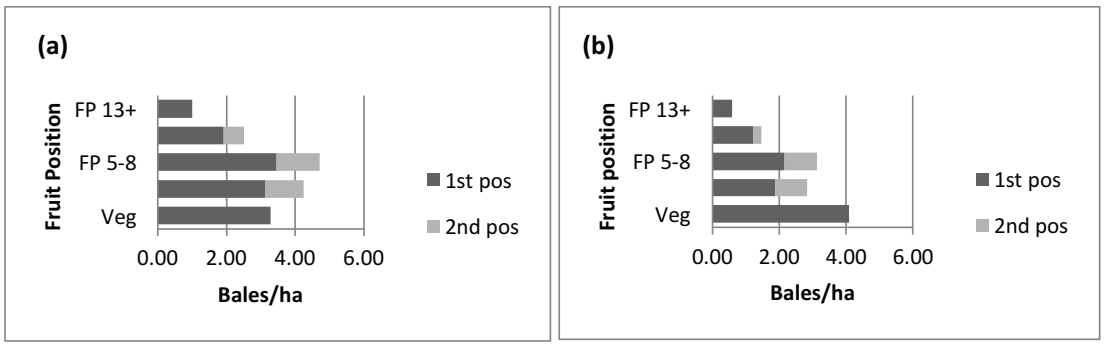

Figure 2. Yield (bales/ha) of hand picked cotton separated into fruiting branch positions (FP) (227 kg lint bales) for (a) 1 m row spacing and (b) 1.5 m row spacing (yield/brown ha)

There was a very strong linear correlation between the number of bolls per m2 and yield (R2 = 0.99) for both 1 m and 1.5 m cotton (see Fig. 3). This agrees with Worley *et al*. (1974) and Jones *et al*. (2014) working in South Carolina and Texas U.S.A., respectively (Worley *et al*. 1974; Jones *et al*. 2014). Furthermore bolls/m2 is considered the primary factor to historical yield increases in Australian cotton (Constable*et al*. 2001).

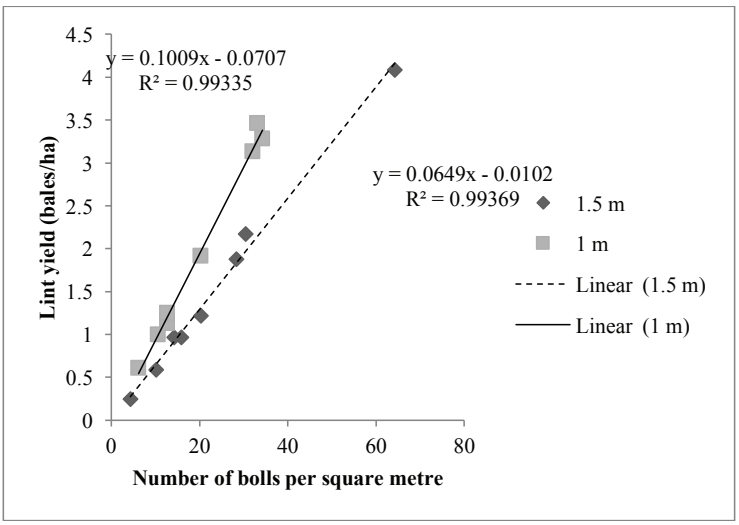

Figure 3. Relationship between the number of bolls (per m2) and yield (in 227 kg bales/ha) across all segments.

Fibre quality

Overall there were no considerable differences in fibre quality between the two row configurations. Both 1 m and 1.5 m cotton exceeded the parameters set by the Australian cotton industry of >1.125 inches fibre length and >29 g/tex fibre strength, respectively (Bange *et al*. 2009). There were slight changes in fibre quality in the segment picks. Fibre length was consistently longer and less variable in the 1.5 m cotton compared with 1 m cotton ($P < 0.031$) (Fig. 4). The 1 m cotton showed considerable variation in fibre length throughout the different fruiting branch positions. The 1.5 m cotton was consistently approximately 1.25 inches, whereas the 1 m cotton was approximately 1.2 inches and shorter in the vegetative branches (1.18 inches). Fibres from the 1.5 m cotton were slightly stronger than 1 m cotton ($P < 0.020$). The 1.5 m cotton consistently took >31 g/tex to break, whereas the 1 m cotton was not as strong at <31 g/tex except for the vegetative fruiting positions (<30 g/tex) (Fig. 5). This improved fibre quality in wider row spacing could indicate less water stress during fibre elongation and is one of the major drivers of using this in rainfed systems (Bange *et al*. 2005). There may also have been less synchronous demand for carbohydrates in the wider row spacing indicated by the differences in fruit distribution.

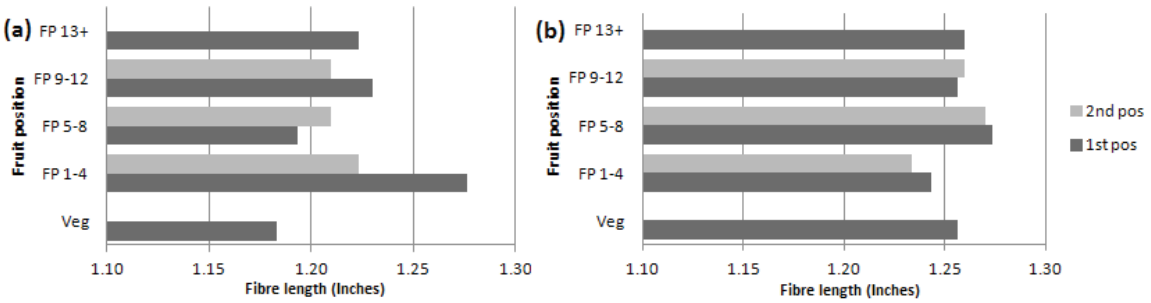

Figure 4. Fibre length (inches) of hand picked cotton in separate fruiting branch positions (FP); (a) 1 m row and (b) 1.5 m row spacing. Fibre length was measured in decimal inches by the High Volume Instrument (HVI) (1 inch = 25.4 mm).

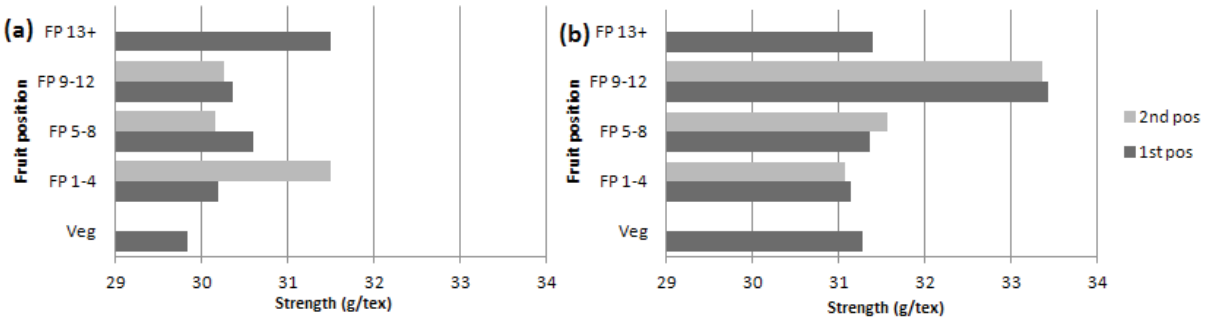

Figure 5. Fibre strength (g/tex) of hand picked cotton in separate fruiting branch positions (FP) in (a) 1 m row and (b) 1.5 m row spacing.

Estimated water use provided by Auscott showed that the 1.5 m cotton used 30% less water (7.27 ML/ha), compared with the 1.0 m cotton (10.43 ML/ha). The water saving of 3.2 ML/ha played a role in reducing costs of 1.5 m cotton to compensate for the reduction in yield compared with 1 m cotton and this saved water would allow for more hectares of cotton to be grown and overall a more profitable farming system. Estimated gross margins showed that both row configurations produced a similar gross margin of $2,000 per ha (detailed calculations not presented). Although yields were higher with 1 m row, 1.5 m row had reduced costs due to savings in irrigation water ($474 /ha) and technology fees ($133 /ha). Technology fees are charged based on the actual green hectares grown, i.e. 100% of the fees are applicable for 1 m row, while only 66.7% of fees are applicable for 1.5 m cotton and skip row spacing as cotton plants represent only 2/3 of the total land area. In the 2014/2015 cotton season, Auscott Warren has installed Mace meters to measure total water applied and capacitance probes to measure crop water use in each row configuration. More precise quantification of crop water use is essential for estimating water use efficiency.

Conclusions

The 1 m cotton out yielded the 1.5 m cotton by 1.8 bales/ha (16%). There was a small improvement in fibre quality in the 1.5 m cotton compared with the 1 m cotton, however in both treatments all fibre parameters exceeded the industry requirements. Handpicked segments revealed that the majority of the fruit in 1 m cotton came from position 1 of fruiting branch positions 1-8 whereas in the 1.5 m cotton a high proportion of fruit came from the vegetative fruiting branches. Gross margins of the two systems were remarkably similar at $2,000/ha. Future research needs to quantify water use to provide more information to improve decision making.

Acknowledgements

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The effect of fertiliser placement and row spacing on plant establishment and grain yield of three broad leaf (*Lupinus albus*) and three narrow leaf (*Lupinus angustifolius*) lupin varieties

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Abstract
Lupin agronomy experiments were established to investigate the effects of row spacing and banding starter fertiliser at sowing on crop establishment and grain yield of lupins. The experiments were conducted at Merriwagga in central west NSW in 2011, 2012 and 2013. Treatments included variety, three row spaces of 25, 50 and 75 cm targeting 45 plants/m^2 and starter fertiliser banded at sowing using the rates of zero and 60 kg/ha. The banding of 60 kg/ha of starter fertiliser with the seed at sowing significantly ($p>0.05$) reduced established plant number of all varieties in each year. The largest reduction in established plant number (63%) occurred at the wider row spacing of 75 cm in 2012. The concentrated amounts of fertiliser in the wider rows combined with intra-row crop competition reduced established plant numbers more than in the narrower row spacing of 25 cm. There was no increase in grain yield with the application of starter fertiliser in two of the three years at this site. As row spacing increased from 25 cm to 75 cm, grain yield decreased by 1.02 t/ha in 2011 to as little as 0.15t/ha in 2012. Averaged across years, grain yield decreased by 29% as row spacing increased from 25 cm out to 75 cm. *L. albus* was generally higher yielding than *L. angustifolius* in each of the three years at this site. In this environment the application of between 5.5 and 7.2 kg/ha of phosphorus banded with the seed has been shown to reduce crop establishment and grain yield, especially at the wider row spacing.

Key words
Phosphorous toxicity, row spacing, crop establishment, fertiliser banded

Introduction

Phosphorus (P) is an essential nutrient for the growth of agricultural crops in south eastern Australia. P is a non-renewable resource and often limits crop production unless supplied as fertiliser (Lambers et. al., 2006). The management of soil P and input of P as fertiliser is important for early crop growth and development.

Lupin spp are able to take up phosphorous from the soil via vesicular-arbuscular (VA) endophytes in the form of mycorrhizal roots (Trinick, 1976). Trinick (1976) found that the addition of small amounts of phosphorous (10 µg P/g soil) limited VA formation on the roots and at levels as high as 100 µg P/g soil VA infection was absent. White lupin (*Lupinus albus* L.) has the ability to develop proteoid root systems to extract P from the soil, even in P deficient situations. Keerthisinghe et al. (1998) found that proteoid root formation was suppressed at concentrations of 25 µg P/g soil. Supporting these findings, grower observation and anecdotal evidence from western NSW reported crop establishment issues when P fertiliser was applied with the lupin seed at sowing.

The shift in farming practice from mixed farm enterprises to continuous cropping has led to the development of diverse rotations of which pulse crops are an integral component. In the Western region of the southern NSW cropping zone, pulse crops account for 25% of the cropping area, and some 15% of this is lupins (Pers. Comm., Barry Haskins, 2015). The cost of fertiliser is a significant one for growers involved in crop production. The question then is can we manipulate the row spacing of the lupin crop or the amount of starter fertiliser applied at sowing without reducing grain yields? This paper reports on three field experiments from the Variety Specific Agronomy Packages Project conducted between 2011 and 2013 at Merriwagga in Western NSW. The experiments were investigating the impact of row spacing and fertiliser placement on lupin crop establishment and grain yield.

Materials and Methods

Field experiments were conducted on the Muirhead's property "Palomar" at Merriwagga the soil type is a red sandy loam, pH was slightly acidic ranging from 5.3 to 5.7 in $CaCl_2$. Site description and treatments are listed in Table 1.

Table 1. Experimental treatments of three lupin trials at Merriwagga in 2011, 2012 and 2013.

Year	Varieties	Sow date	Colwell P mg/kg	Fertilser rate	Row Space cm	Herbicide
2011	Kiev Mutant, Rosetta, Luxor, Mandelup, Jenabillup, PBA Gunyidi	21 April	20	0 and 60kg/ha Superfect	25,50,75	Roundup CT 1.5L/ ha + Stomp 1.2L/ ha+0.7kg Terbyne
2012	Kiev Mutant, Rosetta, Luxor, Mandelup, Jenabillup, Wallan 2333	21 April	32	0 and 60kg/ha Granulock	25,50,75	2L/ha Roundup DST + 900g/ha Simazine
2013	Kiev Mutant, Rosetta, Luxor, Mandelup, Jenabillup, Wallan 2333	30 April	39	0 and 60kg/ha Granulock	25,50,75	1L/ha Roundup CT+1kg/ha Terbyne

Note: Granulock 15 (14.3N, 12P,10.5S), Superfect (0N, 8.8P, 11S, 19.1Ca)

The starting seasonal conditions in 2011 and 2012 were similar with very wet summers (150 mm and 240 mm respectively) leading to good moisture conditions at sowing. Growing season rainfall (GSR, April – October) in 2011 and 2012 was 137 mm and 79 mm respectively. In contrast to the first two seasons, 2013 was a drier summer (60 mm) and sowing was into marginal moisture with a GSR of 187 mm. The long term average GSR for Merriwagga is 193 mm. Varieties remained consistent throughout the trials; however PBA Gunyidi was used in 2011 and replaced with Wallan_2333. The trials were sown with a cone seeder set up with Morris contour drill tines (12 mm knife point and press wheels) with a single shoot. The target plant population was 45 plants/m^2. Starter fertiliser (Superfect in 2011 and Granulock 15 in 2012 and 2013) was applied with the seed at 60 kg/ha regardless of row spacing, therefore there was more fertiliser in the wide row space plots compared with the narrower row spacing.

Results

Crop establishment

As row spacing increased from 25 to 75 cm there was a significant ($p=<0.05$) decrease in crop establishment (Table 2). Established plant numbers were significantly ($p=<0.05$) lower when fertiliser was applied with the seed in the first two years (Table 2). There was a 67% reduction in established plant numbers in 2011and a 31% reduction in 2012 when fertiliser was banded with the seed. There was no difference in 2013. There was no significant difference in crop establishment between varieties.

Table 2. Lupin plant establishment (plants/m2) at Merriwagga

Row space (cm)	Fertiliser	2011	2012	2013
25		24	61	52
50		18	43	39
75		11	39	33
lsd		4.1	5.4	4.3
	Zero	27	56	
	Plus	8	39	
lsd		2.8	2.0	

Grain yield

There was no significant difference (*p=<0.05*) in grain yield averaged across the six varieties from row spacing, apart from 2011 where the narrow spacing of 25 cm was significantly higher (Table 3). The yield potential of lupins declined in each year as row spacing was pushed to 75 cm.

Table 3. Effect of row spacing on lupin grain yield (t/ha) at Merriwagga

Row spacing	2011	2.012	2.013
25	2.28	1.29	1.15
50	1.81	1.30	1.26
75	1.26	1.15	1.05
lsd	201	ns	ns

There was a significant interaction (*p=<0.05*) between fertiliser application and row spacing on grain yield

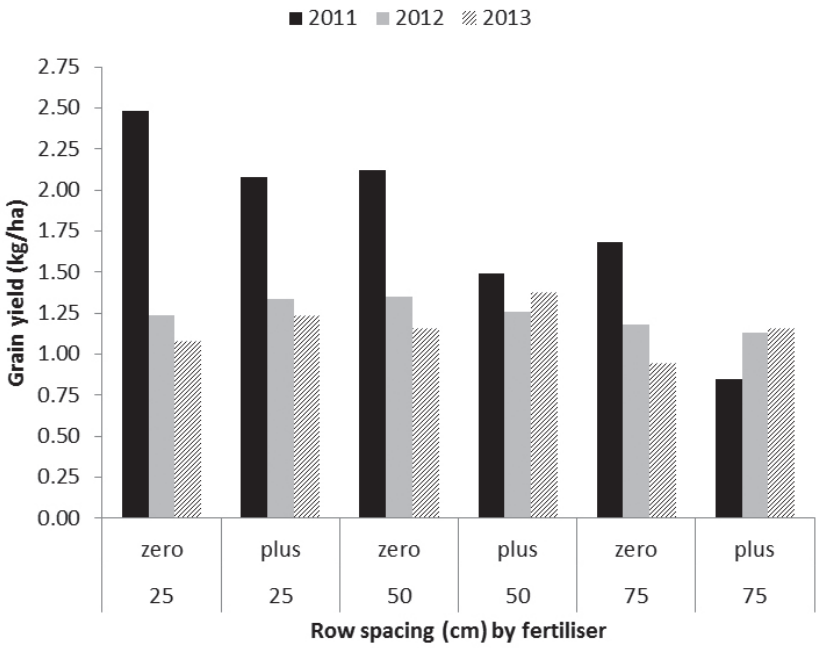

Figure 1. The effect of row spacing and fertiliser application on Lupin Grain yield (t/ha) at Merriwagga in 2011(lsd 0.204), 2012 (lsd 0.206) and 2013 (ns).

The application of starter fertiliser decreased grain yield in 2011 and increased yield in 2013. There was no significant effect in 2012 (Table 4). The addition of starter fertiliser in 2011 significantly reduced crop establishment numbers and this may have confounded the resulting grain yields.

Table 4. Lupin grain yield (t/ha) averaged across varieties, row spacing and fertiliser application rate at Merriwagga

Fertiliser	2011	2012	2013
Zero	2.09	1.26	1.06
Plus	1.47	1.25	1.25
Lsd	0.08	ns	0.14

There was a significant difference (p=<0.05) in grain yield between varieties in all years (Table 5). The broad leafed Albus varieties generally out yielded the narrow leaf Angustifolius varieties at this site.

Table 5. Grain yield (t/ha) of lupin varieties at Merriwagga

Genotype	2011	2012	2013
Kiev Mutant	1.75	1.35	1.33
Luxor	1.85	1.29	1.57
Rosetta	1.68	1.20	1.62
Mandelup	1.88	1.12	0.60
Jenabillup	1.80	1.17	0.89
PBA Gunyidi	1.73		
Wallan 2333		1.36	0.91
PBA Barlock			
lsd	0.15	0.12	0.23

Conclusion

As row spacing increased crop establishment numbers decreased in all years. The concentration of fertiliser at 75 cm row spacing's reduced crop establishment numbers in all years, possibly as a result of intra row competition and the higher rates of fertiliser applied in-row to maintain the rate of 60 kg/ha across all row spacing's. The application of starter fertiliser banded with the seed reduced lupin crop establishment numbers in two of the three years. Trial results from the project, 'Expanding the Use of Pulses in South-Eastern Australia (DAV00113)' showed that banding 20kg/ha of P with chickpea seed significantly reduced crop establishment, whilst separating the fertiliser and seed also reduced crop establishment when the rate reached 30kg/ha of P.

Applying starter fertiliser at sowing to lupins had a mixed effect on the grain yield of lupins. There is not enough evidence from these trials to conclude if there was a consistent positive or negative response in grain yield. There was a significant reduction in grain yield in the first year and no difference in 2012 and a significant increase in 2013. What is apparent from these trials is that in an optimum season under favourable conditions, row spaces of 75 cm have a lower yield potential than narrower rows of 25 and 50 cm. The grain yield in these trials is impacted by the reduction in established plant numbers, especially in 2011.

The interaction between row spacing and fertiliser application was only recorded in 2011 and 2012, both seasons had drier winters. There was no interaction in 2013 possibly due to the wet period in June and July after seeding. There was a significant yield reduction as row spacing increased from 25 to 75cm in 2013 and a general trend of lower yields in each of the other seasons at 75 cm. From these trial results grain yield is compromised when row spacing of lupins exceeds 50 cm.

The results from these trials over three years suggest that the banding of fertiliser with the seed at sowing significantly reduces plant establishment and can have a detrimental impact on grain yield. Applying zero fertiliser did not have an impact on crop establishment; however the long term sustainability of the cropping system could be placed under pressure if P is removed from the rotation even for one season.

Acknowledgements

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Does varying sorghum row configuration stratify soil nitrogen?

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Abstract

Double skip row configurations have been adopted as standard practice in North West NSW to improve the reliability of grain sorghum production. However, the possibility of soil nitrogen becoming stratified in the skip areas where sorghum plants are not grown has not been previously considered in this region.

The ability of sorghum plants to extract nitrogen evenly across the paddock has been examined through a series of row configuration trials conducted over several seasons. Sorghum roots have been shown to extract water from the middle of the double skip area, however there is often more remaining water in this area when compared to under the plant row. It was hypothesised that the same trend could occur for soil nitrogen.

Four trials were conducted from 2009 – 2013 at Cryon, Mungindi, Rowena and Tulloona in North West NSW. Four different sorghum row configurations were established: solid, single skip, super-wide and double skip. Following harvest soil nitrogen was measured both on the row and mid row for all treatments plus in the centre of the skip for the double skip treatment to a depth of 120 cm. Analysis of the nitrogen levels was used as an indicator of possible stratification across a paddock. Grain yields in these trials declined as effective row spacing increased with solid plant yielding significantly more than double skip, in both sites where significant differences were measured. Soil nitrogen results from the Cryon and Rowena trials showed no difference in the remaining soil nitrogen across the configurations. At the Tulloona trial significant differences in remaining nitrogen were measured but no clear pattern with configuration was evident. Only at the Mungindi site was additional nitrogen found in the skip areas.

Key words

Nutrient, spacing, rotation impacts, core position

Introduction

Grain sorghum is the main summer crop in northern NSW and one of the few rotation crops which growers west of the Newell Highway have been including as alternatives to their winter cereal dominant; wheat and barley; rotations. The average area sown to grain sorghum in North West NSW is 27,600 ha annually (Scott, 2012). There is potential for this area to grow considerably if the reliability of sorghum yields could be improved in combination with profitable returns. Currently the majority of the crop is sown using skip or super wide row configurations, with double skip being the most popular, as this also predisposes the crop to the least level of risk in terms of total crop failure. This concept is supported by research in the more favourable production areas in NE Australia which have shown that systems using skip configurations can reduce the risk of crop failure but often results in reduced yields (Whish et al. 2005). Apart from individual crop profitability there is a need to consider the rotation impacts of sowing skip row sorghum. As part of a project focused on improving the reliability of sorghum in this zone, finishing soil nitrogen was measured as an indicator of the remaining soil nitrogen both across and down the soil profile.

Method

Four grain sorghum trials were conducted in the 2009-10 to 2013-14 seasons. Trial sites were located at Cryon (near Walgett), Mungindi, Rowena and Tulloona in North West NSW. The trials used three hybrids, MR43, MR Bazley and 2436 which were sown each season at three of four plant populations; 15, 30 and 50,000 plants/ha or 30,50 and 70,000 plants/ha. Four row configurations were included; 100 cm solid plant, single skip, double skip and a 150 cm super wide.

The trials were all sown into paddocks which had been long fallowed from wheat. Trials were planted using a Monosem precision planter and Trimble guidance system. The trial was fully factorial in a split plot design to allow blocking by configuration and population to aid in trial sowing. Three replicates were included for each treatment. Trial plots were on average 8 m long and between 4 and 8 m wide depending on the configuration. Only the two centre plant rows of each plot were harvested. Each trial was harvested using a

KEW header and weighed to determine final grain yield and quality results. Final grain yields were adjusted to 13.5% moisture content in line with current receival standards.

Following harvest each of the MR 43 plots only were soil cored to a depth of 120 cm to obtain finishing soil nitrate levels. The solid, single skip and super wide treatments had two soil coring positions from within the plot, firstly an "on row" core, which was on the sorghum plant row and secondly a "mid row" core taken halfway to the next sorghum row. The double skip plots had an additional core taken from the centre of the skip area referred to as the "skip" coring position. Soil cores were taken from all plant populations; however the results compare analysis of the row configuration and soil coring position only.

Results

Grain yield

In two of the four trials; Mungindi and Rowena; grain yields declined as effective row spacing widened (Table 1), that is the 100cm solid plant yielded more than the single skip and super wide; which were comparable and all were higher yielding than the double skip configuration. In the remaining two trials, there was no significant difference in the grain yields from the four row configurations. Both of these trials were in below average yielding conditions due to dry seasonal conditions.

Table 1. Grain sorghum yield across configurations

Site/ Row Configuration	Cryon 0910	Mungindi 1011	Rowena 1112	Tulloona 1314
Solid (1.0m)	1.65	5.38_{a}	5.24_{a}	1.04
Single Skip	1.67	4.28_{b}	4.59_{b}	1.07
Super wide (1.5m)	1.73	3.84_{bc}	4.73_{b}	1.02
Double Skip	1.68	3.41_{c}	3.52_{c}	1.04
L.s.d	*n.s.d.*	*0.78*	*0.37*	*n.s.d*

Finishing soil nitrogen

(a) Cryon near Walgett, 2009-10

There was no significant difference in the remaining soil nitrogen when comparing row configurations in the on row and mid row coring positions. On average there was 36.73 kg of nitrogen remaining in the profile to a depth of 120 cm (Table 2). Further analysis of the double skip treatments (Table 3), including comparison of the on row, mid row and skip core position also showed no difference in the remaining soil nitrogen.

(b) Mungindi, 2010-11

At the Mungindi site there were significant interactions between configuration and the position of nitrogen across the rows, with more nitrogen remaining in the mid row area of the double skip treatment compared to all other treatments (Table 2). When including the skip coring position into the analysis, it is evident that there is close to double the amount of nitrogen available in the mid row and skip areas as there is on the sorghum row.

(c) Rowena, 2011-12

The remaining soil nitrogen levels were similar to those from the Cryon site in 2009-10, with on average 30.75 kg N/ha remaining. There was no significant difference in the amount of nitrogen remaining either across the configurations or comparing between the coring positions.

(d) Tulloona, 2013-14

The remaining soil nitrogen was quite high at this site, with on average 56.40 kg N/ha. When comparing across configurations, there was more nitrogen in the solid plant on row position than the other treatments. There was also a large bulge of nitrogen remaining on row in the double skip treatment (Table 2). There was no significant difference in the nitrogen remaining between the three coring positions in the double skip treatment.

Table 2. Finishing soil nitrogen both on row and mid row across configurations (0-120cm)

Configuration	Core Position	Site			
		Cryon 0910	Mungindi 1011	Rowena 1112	Tulloona 1314
Solid	On	32.90	28.60_{b}	31.72	129.49_{a}
	Mid	40.36	25.00_{b}	30.34	39.60_{bc}
Single Skip	On	38.31	23.60_{b}	29.93	32.74_{c}
	Mid	34.53	34.00_{b}	31.54	37.24_{bc}
Super wide	On	37.06	28.20_{b}	28.35	36.21_{b}
	Mid	39.13	32.90_{b}	30.96	77.42_{b}
Double skip	On	33.69	38.50_{b}	32.19	70.25_{b}
	Mid	36.50	79.40_{a}	30.97	28.16_{c}
Lsd		*n.s.*	16.34	*n.s.*	42.43

Table 3. Finishing soil nitrogen in the double skip treatments (0-120 cm)

Configuration	Core Position	Site			
		Cryon 0910	Mungindi 1011	Rowena 1112	Tulloona 1314
Double skip	On	33.69	38.50	32.19	70.25
	Mid	36.50	79.40	30.97	28.16
	Skip	36.53	75.20	34.22	45.09
Lsd		*n.s.*	20.18	*n.s.*	*n.s.*

Discussion

Nitrogen results for two sites Cryon and Rowena showed no significant impact of varying row configuration on remaining soil nitrogen either on row, mid row or even in the skip area. Interestingly at both of these sites, no nitrogen was applied pre-plant. In contrast at both the Mungindi and Tulloona trial sites, nitrogen was applied as fertiliser at or prior to sowing plus additional nitrogen was present in the soil profile, supplying between 80 - 120 kg N/ha to each crop.

Soil cores taken post-harvest at Tulloona in 2013-14 showed a large amount of nitrogen was still unused in the profile. Most likely this was due to low in crop rainfall which meant nitrogen fertiliser was not utilised by the sorghum crop. This is supported by the low grain yields (Table 1) of around 1.0 t/ha. The “on row” core in the solid plant treatment contained the largest amount of nitrogen, close to 130 kg/ ha. There were also significant amounts of nitrogen in the “mid row” area of the super wide treatment and “on row” in the double skip treatment. At the Mungindi site where grain yields were significantly higher, between 3.4 – 5.4 t/ha the remaining soil nitrogen levels were quite even across configurations both “on row” and “mid row” with the exception of the double skip treatment where close to double the amount of nitrogen was detected both in the “mid row” and also in the skip area of the plots.

Conclusion

There were large differences in sorghum grain yield across the four row configurations from two of the sorghum trials conducted. In these two trials, the solid plant outyielded the single skip and superwide configurations which were comparable while the double skip configuration yielded significantly less than all other three treatments. In the remaining two trials there was no significant difference across row configuration but in both of these trials average yields were extremely low as well, between 1.0 – 2.0 t/ha due to drought stress.

At only one of the four trial sites was data collected which supported the concept that nitrogen could possible become stratified in the skip areas of skip row configurations. At two of the trial sites, no significant difference could be detected and at the third trial, significant differences were measures but a pattern to explain the results could not be established. Additional data is needed to either support or refute the notion that nitrogen can become stratified in the skip areas of sorghum.

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Extent and attitudes of growers to dry seeding in the agroecological zones of Western Australia

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Keywords
Dry seeding, wheat, canola, survey

Abstract
Seeding into dry soil before the break of the season has been widely adopted in Western Australia; however the extent, risks and management of dry seeding are not well documented. One hundred and five face to face surveys were completed by growers across the agro-ecological zones of Western Australia to gather information on the extent of dry seeding and what perceptions they had on the benefits and risks. In addition, an existing Planfarm 2011 client survey (197 growers) was used to determine dry seeding practices in that season. Based on these surveys, dry seeding was practiced on half of the farms from the low rainfall zone, 43% in the medium rainfall zone and 26% in the high rainfall zone. Of the farms that practiced some dry seeding the mean proportion of the farm dry seeded was similar (23-32% of total farm area). Farmers dry sowed 80-100% of their canola and lupin crop while 30% of their wheat was dry sown on average. Weed control was ranked as the most important risk, followed by poor crop emergence and then frost. The ability to start sowing by date was perceived to be the most important benefit from dry sowing and growers were more confident to dry sow after a wet summer. Implications of the findings and future research directions are discussed.

Introduction

More than 90% of farmers in the West Australian wheat-belt undertake no-tillage farming where crops are sown in one-pass with a knife point combine (D'Emden and Llewellyn 2006; D'Emden, Llewellyn et al. 2008). The major advantage for crop production over the last 30-40 years has been timelier seeding and increased yield potential of crops sown earlier after the break of the season (D'Emden and Llewellyn 2006; D'Emden, Llewellyn et al. 2008). However, over the last decade farmers have had to make significant adjustments to their seeding program to continue receiving the benefits of the no-tillage system and remain profitable. With farm sizes increasing and the high cost of machinery farmers are having to seed over a longer time frame. In WA farms also experience low and highly variable rainfall (often late) in the planting window resulting in low water-use efficiency and yields (Lawes, Oliver et al. 2009). As a result, there is anecdotal evidence that farmers have started sowing a larger proportion of their wheat crops early before the break of the season into dry soil, therefore extending their planting window. This allows them to complete their cropping program in the required time regardless of the amount and timing of opening rainfall despite risks of false breaks, poor germination and potential frost risks.

While dry seeding has been adopted in Western Australia, especially in the lower rainfall agronomic zones for lupin and canola, the extent and management of dry seeding are not well documented for wheat crops. Consequently, a survey of 105 growers in the low, medium and high rainfall zones of Western Australia was conducted in 2012. An existing Planfarm Database of 196 growers was used to examine the extent to which dry seeding was practiced. The surveys were also used to assess the relationships between various climatic factors across the WA wheat belt, potential farm yield benefits in response to the amount of dry seeding practiced, growers management practices of dry sowing, and their attitudes towards the risks and benefits of dry sowing.

Materials and method

A state-wide survey of grain growers was conducted across the agro-ecological zones to gather information on current practices used when crops were sown dry. The Western Australian No-Tillage Farmers Association (WANTFA) surveyed 105 growers across three agroecological zones. The survey was designed to gain insight into how and why growers seeded dry and what perceptions they had on the practices benefits, disadvantages and opportunities. In this paper results for dry sowing adoption and farmer's perception of risk are presented. Surveys were completed by farmers at agricultural field days, events and online via e-mail. In

addition, a Planfarm 2011 client survey (197 growers across the State) that includes questions on dry seeding and equipment used was also analysed. A multivariate analysis was undertaken on the Western Australian No-Tillage Farmers Association survey data using Genstat, 14th edition. Planfarm Benchmark Survey: The database was grouped into four groups (0%, 0-10%, 10-20%, 20-30% and >30% dry seeding). We then examined any changes in farm level wheat yield for these four groups. In the data the area of the farm dry sown refers to all crop species. The available data did not distinguish between crops species. In terms of the yield benefits we focused on the wheat yield only. Our assumption was that early sowing of other crops due to dry seeding would mean that any subsequent wheat crops were also planted earlier.

Results and discussion

Extent of Dry Seeding

Our results indicated that dry seeding was practiced most widely in the low rainfall zone, to a lesser extent in medium rainfall zone, and much less in the high rainfall zone (Table 1, figure 1). Half of the farms in the low rainfall zone practiced some dry seeding. This decreased to 43% in the medium rainfall zone and 26% in the high rainfall zone. Of the farms that practiced some dry seeding the mean proportion of the farm dry sown was similar (23-32% of total farm area) between rainfall zones. There was a wide range in the proportion of farm dry sown, with some farms in the low and medium rainfall zones that dry seeded their whole farm in 2011 (data not shown). Overall a large number of the farms were doing comparatively small amounts of dry seeding (<10%) with a much smaller number of farmers practicing widespread (>50%) dry seeding (Figure 1).

Table 1 Proportion of farms dry seeding and proportion of farm dry seeded for high, medium and low rainfall zones in 2011 Planfarm Database.

Rainfall zone	Total number of farms	Proportion of farms practicing some dry seeding	Proportion of farm dry sown[1]
High	31	26%	30%
Medium	92	43%	23%
Low	74	51%	32%
Total	197	44%	27%

[1] Data are averages from farms that practiced some dry seeding.

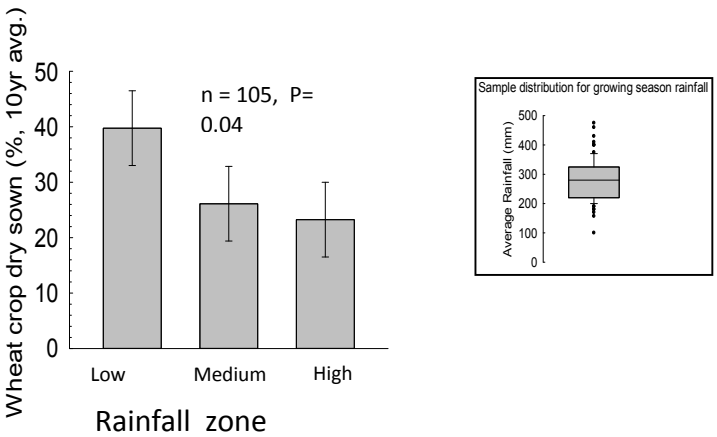

Figure 1 Proportion of wheat sown dry in the WANTFA survey. Figures represent the average percentage of wheat dry sown on their property over the last ten years.

Perceived risks with dry sowing

Participants in the WANTFA survey were asked to rank risks from least important to most important (Figure 2). The results suggest that weed burden was the most important risk to manage when dry sowing followed by frost and poor emergence (Figure 2).

In open ended questions most farmers perceived that dry seeding was fairly low risk if they have sub soil moisture. The farmers surveyed indicated the biggest benefit to dry seeding were timeliness of operation and making the most of rainfall. The answers revealed that some farmers preferred to stick with dry sowing canola or only dry sowing wheat into clean paddocks if it didn't rain in the preferred timeframe. Ideally many growers would like it to rain in early April so they can get a good knockdown on germinated weeds before sowing the wheat crop, however over the past ten years this has become a less likely occurrence. The overriding response from farmers was that dry seeding has become the most economical way of sowing their desired cropping program in the right timeframe. Buying more seeders or increasing machinery size would be an alternative but farmers indicated that this was a cost prohibitive option. Growers commented that in low rainfall years, dry sowing could be the difference between successful implementation of their cropping program or crop failure after missing out on vital early rainfall.

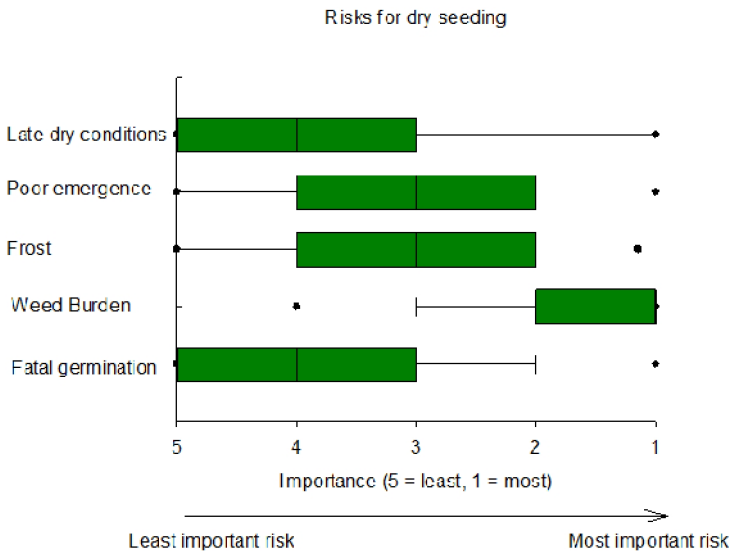

Figure 2 Perceived risks of growers when making the decision to sow crops dry

Grain Yield

When a comparison was made between the WANTFA survey results discussed previously and the Planfarm survey results (Figure 3 a and b) there were striking similarities in the trends for dry and wet sowing. The WANTFA survey considered farm wheat production records recalled by farmers for 4 previous seasons (2008-2011). By comparison, the analysis undertaken of Planfarm client data considered observed farm yields and dry sowing percentages for all crops grown on farms in one season (2011). Despite these differences in approach, Figure shows similar trends towards higher grain production with dry seeding in both analyses

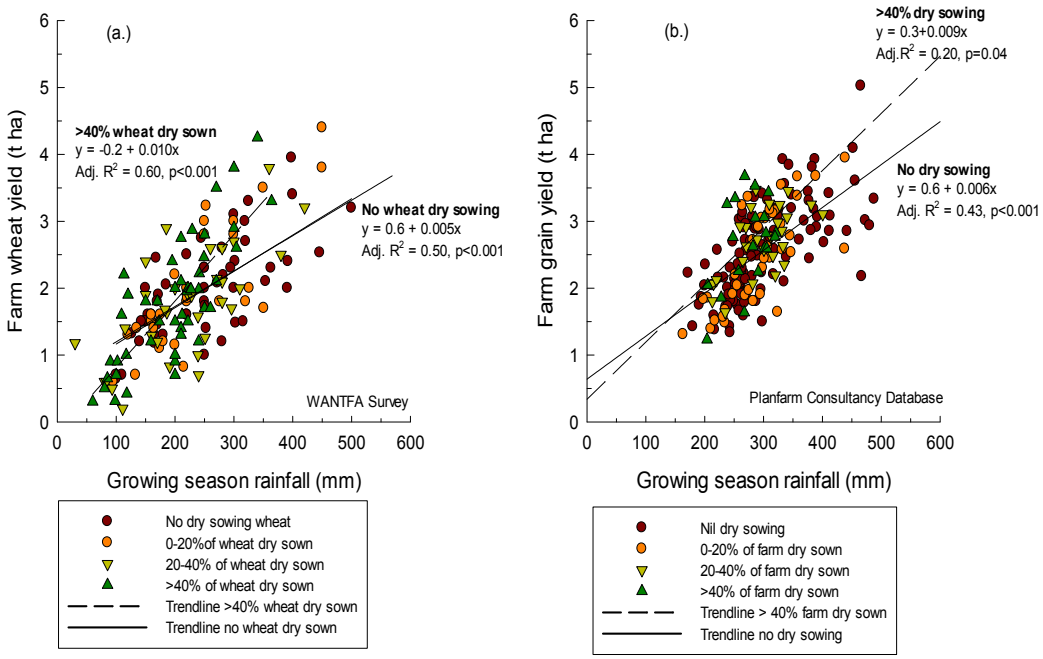

Figure 3 Comparison of (a) WANTFA random survey data (2008-2011) and (b) Planfarm consultancy data (2011). The graphs in the Figure show the relationship between farm yields and rainfall with respect to the percentage of wheat crop (WANTFA, left) and all crops (Planfarm, right) dry sown on farms. Lines have been fitted through the categories >40% area dry sown (green triangles) and nil dry sowing (red circles) for comparison.

Conclusions

The surveys showed that dry seeding was practiced most widely in the low rainfall regions with approximately 50% of farms practicing some dry seeding. There is an indication of yield benefits in wheat of up to 500 kg/ha from dry sowing in average years. Growers preferred to dry seed crops, rather than wait for a break, because the perception was that it improves overall farm profitability despite not knowing how big that benefit was. Survey participants perceived the major risks to be weed burden followed by poor emergence and frost. Continued seasonal instability and the potential to improve farm profitability with dry seeding is cause for further research to improve dry seeding agronomy.

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Identifying the optimal flowering period for wheat in south eastern Australia: A simulation study

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Abstract
Across the Australian wheat belt, the time at which wheat flowers is a critical determinant of yield. In all environments an optimal flowering period exists which is defined by decreasing frost risk, and increasing water and heat stress. Despite its critical importance, optimal flowering periods based upon simulated yield from long-term climate records have not been comprehensively quantified across Australia's cropping zone. In this study, the widely validated cropping systems model (APSIM-Wheat) was used to predict wheat yield, with reductions in yield applied for frost and heat damage based on air temperatures during sensitive periods. The APSIM-Manager was used to sow a crop on a fixed date at weekly intervals starting from the 1 April to the 15 July of each year. The relationship between flowering date and grain yield was established for 29 locations using 51 years (1963-2013) of climate records. The simulation experiments provided results on potential yields, yield reduction from frost and heat events and interactions with season and soil type. APSIM output for yield and flowering date was split by calculating the means of values between the 20th and 30th percentiles, 45th and 55th percentiles and 70th and 80th percentiles within each sowing date. The peaks of the percentile bands, representing the relationship between sowing date, flowering date and yield, were used to define the optimal flowering period in each location. Optimal flowering periods varied considerably across the Australian wheat belt. The optimal flowering period across all locations ranged between 13 August and 1 November, though the start and end dates, and duration of these periods varied greatly with location. Quantifying optimal flowering periods is vital to identify suitable genotype x sowing date combinations to maximise yield in different locations.

Key words
APSIM, frost, heat, optimal flowering period, simulated yield

Introduction
Infrequent rainfall events, high temperatures during grain fill and the risk of frost at flowering are three major environmental constraints to wheat yield in Australia (Gomez-Macpherson and Richards 1995). Flowering at the optimal period is critical to final grain yield, as it is immediately prior to and during anthesis that grain number is determined. It is also at this time that grain yield is most sensitive to stresses such as extreme high and low temperatures and water stress (Fuller *et al.* 2007; Tashiro and Wardlaw 1990). A combination of environmental factors (soil type, water availability, temperature) influence the start, end and duration of an optimal flowering period which varies greatly across the Australian wheat belt. In addition to the variability of Australian environment types, there is evidence of changing rainfall patterns (Cai *et al.* 2012), and predictions of further rainfall variability, occurrence of high-temperature events (Zheng *et al.* 2012)B. Y.,</author><author>Chenu, K.,</author><author>Dreccer, M. F.,</author><author>Chapman, S. C.,</author></authors></contributors><titles><title>Breeding for the future: what are the potential impacts of future frost and heat events on sowing and flowering time requirements for Australian bread wheat (Triticum aestivium and harsher springs (Kirkegaard and Hunt 2010). Therefore the need to identify the optimal flowering periods for environments in the Australian wheat belt is clear.

Identifying the optimal flowering period for specific environments allows identification of suitable genotype (G) x management (M) combinations allowing yield to be maximised. In contrast to Zheng *et al.* (2012) who used air temperature records to analyse frost and heat patterns of the Australian wheat belt to calculate target flowering windows based on last frost days and first heat days in current and future climates, this study uses APSIM-Wheat to incorporate the effect of drought stress and radiation as well as temperature to define the optimal flowering period for locations in the south eastern Australia wheat belt.

Material and Methods
Site selection and crop simulation approach
Locations were selected to represent environments where wheat is grown in the southern cropping region of

Australia, and based on the availability of accurate soil characterization from the APSoil database (Dalgliesh *et al.* 2009) and patched-point meteorological weather stations from the SILO database (Jeffery *et al.* 2001). The cropping systems model Agricultural Production Systems SIMulator (APSIM) version 7.6 was used to estimate the optimal flowering dates for wheat for locations in the south eastern cropping zone. APSIM is a model for wheat yield that has been extensively validated in numerous studies across southern Australia (Hochman *et al.* 2009), no further validation was undertaken here. The key APSIM modules used in the analysis were Wheat (crop growth and development) and Manager (specifying sowing rules). APSIM-Wheat calculates flowering date by accumulation of thermal time, calculated from the daily average of maximum and minimum air temperatures, and is adjusted by genetic and environmental factors (Ritchie and NeSmith 1991). The length of each phase between emergence and floral initiation is determined by thermal time, and cultivar- specific factors, photoperiod and vernalisation (Ritchie and NeSmith 1991).

Crop management set up

To determine the optimal flowering period for different sites in the southern cropping region of Australia, simulations were run using 51 years (1963- 2013) of climate data. All simulated crops were sown at 150 plants/m2, at a depth of 30 mm, and a row spacing of 300 mm. The cultivar parameters selected represented spring wheat of a mid-fast maturity such as is predominantly grown in SE Australia (e.g. Scout, Spitfire, Trojan etc.). This was based on the APSIM base cultivar with vernalisation sensitivity of 1.5 and photoperiod sensitivity of 3.0. The APSIM-Manager was used to sow a crop on a fixed date at weekly intervals starting from the 1 April until the 15 July of each year. Nitrogen was applied as NO3 with a fertilizer rule, which was maintained above 100 kg/ha in the top three layers of the soil throughout the season such that N did not limit yield. In the simulation, the crop received 15 mm of rainfall at sowing so that it would emerge shortly after it was sown. APSIM assumes crops are grown free of weeds and disease. A reduction for frost and heat damage based on air temperature obtained from patched point meteorological weather stations was applied as per Bell *et al*. (2015). Within APSIM, yield reductions were cumulative for multiple events that occurred during the sensitive stages of plant growth. The combination of management rules and frost and heat rules ensure that the optimal flowering period for each site was calculated solely by the drought pattern, temperature and radiation of an environment. The output used in the analysis was annual grain yield modified for frost and heat damage at different sowing dates and the corresponding flowering dates. The output was split by calculating the means of values between the 20th and 30th percentiles, 45th and 55th percentiles and 70th and 80th percentiles for each sowing date. The peaks of the percentile bands, representing the relationship between sowing date, flowering date and yield, were used to define the optimal flowering period for each location.

Results and Discussions

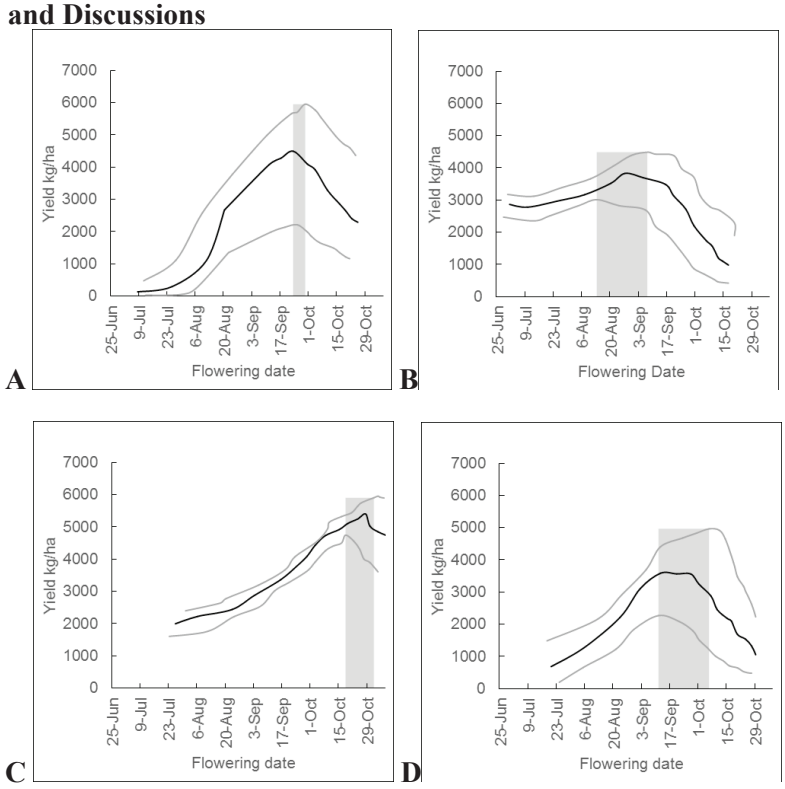

Figure 1: The optimal flowering period of wheat determined by APSIM simulation for A) Dubbo, NSW B) Minnipa, SA C) Inverleigh, VIC D) Urana, NSW. Grey lines represent potential yield for 20-30 and 70-80 percentile bands and the black line represents the 45-55 percentile band. Grey columns are the estimated optimal flowering period defined between peak of 20-30 and 70-80 percentile bands over the 51 year simulation (1963-2013).

Table 1: Summary of the predicted optimal flowering period for an early-mid spring wheat, simulated peak median of frost-heat adjusted yield and corresponding sowing date over 51 years (1963-2013), for 29 locations.

Location	Annual rainfall (mm)	Optimal flowering period		Length of flowering period (days)	Peak median value of frost-heat adjusted yield (kg/ha)	Coinciding sowing date to peak median
		Open	Close			
Waikerie (SA)	258	19-Aug	2-Sep	14	1679	29-Apr
Walpeup (VIC)	331	12-Sep	14-Sep	2	3707	29-Apr
Mathoura (NSW)	360	14-Sep	21-Sep	7	1855	29-Apr
Urana (NSW)	441	11-Sep	6-Oct	25	3583	29-Apr
Longerenong (VIC)	413	3-Sep	8-Oct	35	2906	6-May
Merriwagga (NSW)	356	5-Sep	12-Sep	7	2621	6-May
Nyngan (NSW)	441	17-Aug	28-Aug	11	2162	6-May
Hopetoun (VIC)	342	2-Sep	23-Sep	21	1762	6-May
Kerang (VIC)	356	1-Sep	26-Sep	25	3485	6-May
Lameroo (SA)	385	3-Sep	24-Sep	21	3443	6-May
Tottenham (NSW)	471	6-Sep	8-Sep	2	3322	6-May
Yarrawonga (VIC)	509	24-Sep	5-Oct	11	4068	6-May
Minnipa (SA)	343	13-Aug	7-Sep	25	3827	6-May
Lock (SA)	390	3-Sep	10-Sep	7	3506	6-May
Swan Hill (VIC)	344	17-Sep	1-Oct	14	4037	13-May
Charlton (VIC)	403	22-Sep	6-Oct	14	3265	13-May
Temora (NSW)	510	2-Oct	10-Oct	8	3366	13-May
Condobolin (NSW)	437	25-Sep	1-Oct	6	2149	13-May
Bogan Gate (NSW)	495	5- Sep	2-Oct	27	4309	13-May
Hart (SA)	458	24-Sep	29-Sep	5	4737	20-May
Cleve (SA)	400	28-Aug	16-Sep	19	3984	20-May
Dubbo (NSW)	591	23-Sep	29-Sep	6	4494	20-May
Trangie (NSW)	492	19-Sep	25-Sep	6	5256	20-May
Saddleworth (SA)	493	13-Sep	25-Sep	12	4130	27-May
Bordertown (SA)	479	2-Oct	6-Oct	4	4076	27-May
Cummins (SA)	428	14-Sep	27-Sep	13	4316	27-May
Cootamundra (NSW)	618	9-Oct	25-Oct	16	5087	27-May
Maitland (SA)	502	24-Sep	7-Oct	13	5288	3-Jun
Inverleigh (VIC)	553	18-Oct	1-Nov	14	5400	1-Jul

Chenu *et al.* (2013) illustrated the large variability in rainfall and temperature patterns that wheat crops experience in Australia. Correspondingly, our simulation study shows that the optimal flowering period differs for each environment in the Australian wheat belt. For each of the 29 locations (Table 1) analysed, we have identified a flowering period for an early-mid spring wheat that generated the highest yields over 51 seasons in each environment. The locations ranged from marginal rainfall and light textured soil types such as in Walpeup VIC and Waikerie SA, to high rainfall and heavy textured soil types such as in Dubbo NSW and Temora NSW. The highest peak median yield was in Inverleigh VIC, of 5400 kg/ha. The lowest yielding location was Waikerie, of 1635 kg/ha. High annual rainfall often reflects a cooler growing season in the southern grain-growing region. Higher rainfall and cool growing seasons can also translate into higher yield, and later optimal flowering periods (Table 1).

The optimal flowering period for a wheat of mid-fast maturity, across all locations ranged between 13 August and 1 November. However, the start and end dates varied greatly across the wheat belt with substantial variation in duration of these periods. The earliest flowering start date was at Minnipa SA. The latest flowering start date was Inverleigh. The degree of incline or decline of the percentile curves before or after the optimum for a location illustrates if an optimal flowering period is influenced by frost or drought in an environment. For example, Minnipa percentiles have a gentle incline showing that frost is less of a determinant on flowering period, but heat and water stress (drought) play a larger role as shown by the sharp decline after peak yield is reached (Figure 1B). In comparison, in locations Inverleigh and Dubbo, frost or sub-optimal radiation plays a large role in determining flowering period, as seen by the sharp incline of the percentiles (Figures 1A and 1C).

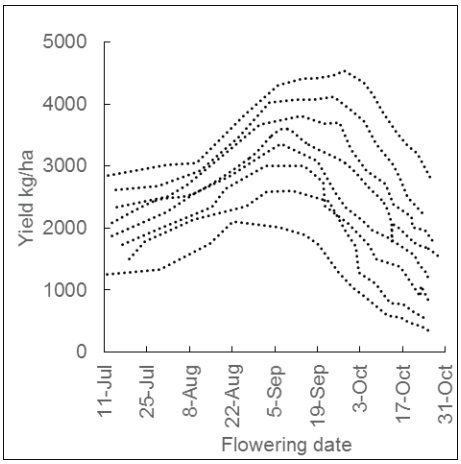

Figure 2: The flowering period for Lameroo, South Australia, split into percentile bands. Dotted lines represent the average of yield and flowering date values within each sowing date between the 10th-20th, 20th-30th, 30th-40th, 40th-50th, 50th-60th, 60th-70th, 70th-80th and 80th -90th percentile bands, for simulated 51 years (1963-2013).

When APSIM output for yield and flowering date is separated into percentile bands (Figure 2), it reveals how optimal flowering date can change from season to season. In a practical sense, given seasonal conditions are unknown at sowing, wheat producers should aim for the peak median flowering date and its corresponding sowing date as this is a reasonable estimate of an appropriate flowering date under the most likely conditions based on historic weather data (Table 1).

Conclusion

Changing rainfall patterns and increasingly variable weather during spring makes achieving timely flowering of wheat crops increasingly critical to yield and farm profitability (Kirkegaard and Hunt 2010). Now that optimal flowering periods have been identified, different G x M strategies can be evaluated in order to achieve these optimal flowering dates in different locations under current and future climates.

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Dry matter partitioning in canola (*Brassica napus* L.) and the impacts on grain yield in the High Rainfall Zone of south-eastern Australia

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Abstract
Crop research in the high rainfall zone (HRZ) of Southern Australia is focusing on improving canola grain yields to more closely reflect the production potential of the region. This research has involved a series of field experiments to identify superior varieties and traits, together with tailored management practices to increase yield. An analysis of data from seven of these experiments was conducted to gain a greater understanding of the genetic, environmental and management (G x E x M) factors influencing yield formation. The dataset provided more than 600 G x E x M combinations from five seasons, 60 cultivars and different management treatments at Hamilton. Seasons were highly variable with annual rainfall ranging between 69% and 143 % of the long term average (LTA) and spring rainfall (Sep-Nov) between 45% and 106% of the LTA. The range in the number of days between sowing and harvest for the 600 combinations was 186 to 236 days. Over the five seasons grain yields for individual treatments ranged from 1.5 t/ha to 9.5 t/ha. The proportion of grain relative to the total amount of above ground dry matter produced between first flower and harvest i.e. post-anthesis harvest index (PAnHI) ranged between 0.3 to 2.6. A PAnHI greater than one indicates that there has been a reliance on translocated DM from the pre-anthesis period. A PAnHI greater than one tended to occur more in drier seasons and for the later maturing winter crops. The significance of environmental factors relative to specific traits is now being further investigated under controlled environment conditions in the field where rain exclusion shelters and irrigation treatments will generate different levels of water stress. This research will determine if there is genetic diversity that can be exploited in translocating more pre-anthesis DM into grain.

Key words
Post-anthesis harvest index, winter canola

Introduction
Winter canola varieties (i.e. those with a vernalisation requirement) have only been commercially available in Australia since 2011. These winter varieties and later maturing spring types have provided yield advantages over the early and mid-maturing varieties of up to 20% across a wide area of the HRZ (Christy *et al*., 2013, Riffkin *et al*., 2012a). This is despite flowering up to four weeks later and filling grain under warmer and drier conditions than the earlier maturing spring types. Variety evaluation and management experiments conducted in the high rainfall zone (HRZ) over the past five years and have shown large differences in phenology, plant height, above ground dry matter (AGDM) accumulation and grain yields between the different winter and spring canola varieties. Data from seven of these experiments was analysed to gain a greater understanding of the genetic, environmental and management (G x E x M) factors influencing yield formation.

Material and Methods
Experiments were conducted on the Department of Economic Development Jobs, Transport and Resources (DEDJTR) research farm at Hamilton in Victoria (37°49'S, 142°04'E) over five years from 2010 to 2014. Soil type at Hamilton is a chromosol and the long term average (LTA) rainfall is 690 mm. The combined dataset which provided more than 600 G x E x M combinations from 60 cultivars and different management treatments on a single site has minimised confounding effects of location and soil type. Experiments included the evaluation of different varieties including spring, winter, semi dwarf, herbicide tolerant (triazine and Imidazolinone tolerance) and conventional types. Management experiments included different N fertiliser rates (0, 25, 50, 175 kgN/ha) and timings (4 leaf stage, stem extension) and the application of an experimental growth regulator at 5 leaf and/or mid stem extension (Riffkin *et al*., 2012b).

The experiments were direct drilled into raised beds on April 30, 2010; April 29, 2011; May 18, 2012; May 7, 2013 and May 8, 2014. Sowing rate targeted 50 plants m-2 and weeds and pests were controlled as required. Quadrat cuts (0.5 m-2 per plot) were taken at the bud visible and 10% flowering stages to determine AGDM. At final harvest, grain yield, yield components and total AGDM were determined from two, one m-2 quadrats per plot. Post-anthesis harvest index (PAnHI) was calculated as;

$$\frac{\text{Grain weight at maturity}}{\text{Total AGDM from first flower to maturity}}$$

Results

The five seasons in which the experiments were conducted were highly variable (Figure 1). Rainfall in 2010 and 2011 were higher than the long term average. However, the higher falls in 2011 were due to exceptionally high events from January to April with lower than average rainfall in November and December. The spring irrigation applied to the irrigation treatments were 44 mm in 2010 and 215 mm in 2011. Rainfall in 2012 and 2014 were below average with only 75% and 45% of the LTA occurring in spring in 2012 and 2014 respectively. As in 2010, rainfall for 2013 provided good growing conditions throughout the year (Table 1).

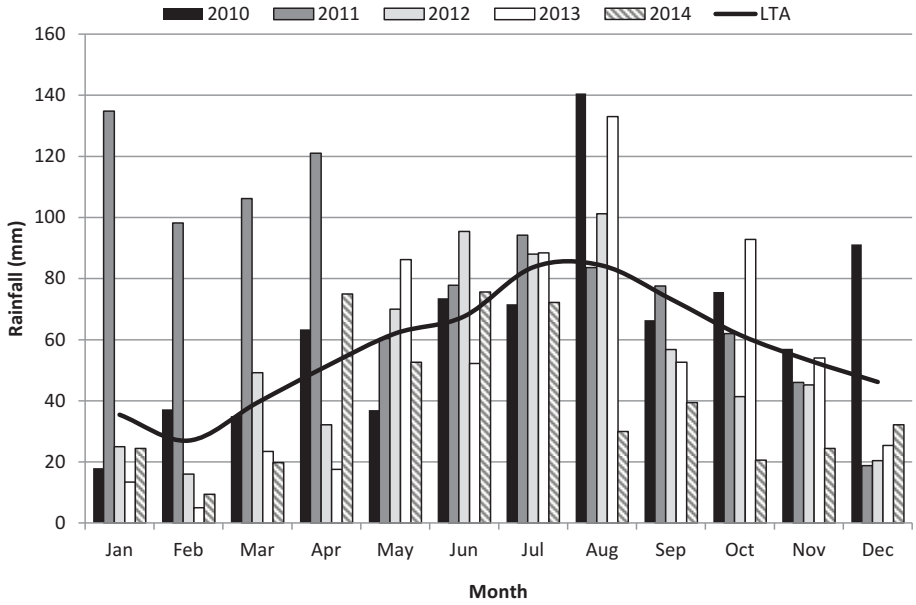

Figure 1. Month rainfall for the five seasons of field experiments (Bars, 2010-2014) and the long term average (line) at Hamilton.

The difference between treatments in the total number of days between sowing and harvest within the dataset was 50 days with the shortest time between sowing and harvest 186 days and the longest 236 days. The winter canola types reached anthesis on average 28 days later than the spring types (mean of all treatments) and accumulated more pre-anthesis AGDM (Table 2). There was little difference in the total amount of rain that fell during the grain fill period with 162 mm for the spring types and 155 mm for the winter types (mean of all years).

Table 1. Annual rainfall, growing season rainfall (GSR) rainfall and spring rainfall (Sept-Nov) for the five seasons of field experiments and amounts as a percentage of the long term average at Hamilton. Amounts do not include irrigation.

	Annual	GSR (A-N)	Spring (S-N)	%LTA (Annual)	%LTA (GSR)	%LTA (Spring)
2010	767	585	199	112	109	106
2011	981	623	186	143	116	99
2012	641	530	143	94	99	76
2013	644	577	199	94	107	106
2014	476	390	84	69	73	45
LTA	685	537	188			

Grain yields for individual treatments within the dataset ranged between 1.5 t/ha to 9.5 t/ha. Mean annual grain yields were between 3.8 t/ha in 2014 and 7.5 t/ha under irrigation in 2010. The winter types tended to yield better than the spring types. Greater HI were generally achieved in the years with higher spring rainfall and under irrigation (Table 2).

Table 2. Mean above ground dry matter (AGDM) at anthesis, grain yields, harvest indices, post-anthesis harvest index (PAnHI) and the proportion of treatments with a PAnHI greater than one for the different seasons between 2010 and 2011 at Hamilton.

Treatment	Anthesis AGDM (Kg/ha)	Grain Yield (t/ha)	Mean PAnHI	%PAnHI >1
2010 Rain fed	5660	6.5	0.52	0%
2010 Irrigated	6060	7.5	0.52	0%
2011 Rain fed	8820	5.6	0.91	30%
2011 Irrigated	9650	6.2	0.96	38%
2012 Rain fed	9790	5.8	0.97	36%
2013 Rain fed	9220	6.3	0.76	10%
2014 Rain fed	8200	3.9	1.14	57%
Spring Types	7590	5.7	0.72	17%
Winter Types	9470	6.2	0.93	30%

Post-anthesis harvest indices for individual treatments ranged between 0.3 to 2.6. Mean PAnHI and the number of treatments with a PAnHI greater than one were generally more in the years where spring rainfall was lower than the LTA (Figure 2). Similarly mean PAnHI and the number of treatments with PAnHI greater than one was higher for winter types compared to the spring types.

Discussion

Different seasonal conditions and canola types influenced dry matter partitioning and provided a wide range in grain yields and HI. Harvest indices were comparable to wheat when the cost of glucose conversion to starch or oil were considered. Generally, PAnHI was higher in the years where spring rainfall was lower suggesting that in these years the dry matter accumulated pre-anthesis contributed more to grain yield than in wetter years where grain yield came more from net assimilation during the grain filling period.

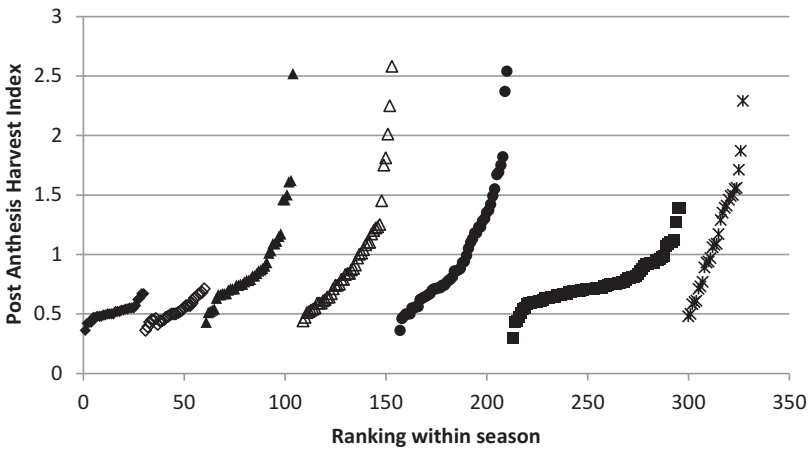

Figure 2. Post anthesis harvest index (PAnHI; proportion grain to total above ground dry matter accumulated between first flower and harvest). Results are from five field experiments from 2010-2014 at Hamilton, 2010; diamonds, 2011; triangles (solid symbols are for rainfed treatments and open symbols are for irrigated), 2012; circles, 2013; squares and 2014; stars (rainfed). Data is ranked from lowest to highest PAnHI within each season.

Winter varieties appeared to rely more on pre-anthesis dry matter to fill grain than the spring varieties. Although the winter varieties flowered considerably later than the spring varieties (approximately four weeks), there was little difference in the total amount of rain that fell during the grain filling periods (7 mm, mean of all seasons). There was also little difference in PAnHI between the irrigated and rainfed

treatments in 2010 and 2011. These observations suggest that factors other than rainfall are influencing dry matter partitioning to grain. The winter varieties had approximately 25% more AGDM at anthesis than the spring varieties. This may have provided a source of reserves for grain filling especially in the drier years. The significance of environmental factors relative to specific traits is now being further investigated under controlled environment conditions in the field where rain exclusion shelters and irrigation treatments will generate different levels of water stress. From this experiment we expect to improve our understanding of environmental factors which influence dry mater partitioning in canola and identify important traits relating to grain yield. This will help inform breeding programs and develop management decisions to give greater, more stable grain yields for growers in the HRZ.

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Novel wheat genotypes for early sowing across Australian wheat production environments

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Abstract
Advances in summer fallow management and no-till seeding techniques have allowed Australian wheat growers to sow earlier than ever before. Research has demonstrated that slow developing cultivars sown early (mid-April) yield more than fast developing cultivars sown late (mid-May) when they flower at the same time. However, over the last century Australian wheat breeders have focussed on cultivars with increasingly rapid development through selection of insensitive photoperiod (Ppd) and vernalisation (Vrn) alleles, and few contemporary cultivars exist that are suitable for sowing early. Breeding programs must begin selecting for slower developing genotypes in order for growers to capitalise on yield advantages from early sowing. This study aimed to inform breeders on the combinations of Vrn and Ppd sensitive alleles that are best suited to early sowing in different production environments. It used near-isogenic lines that vary in alleles of major developmental genes planted at multiple times of sowing at 14 dryland locations across the Australian wheat belt. The fast developing winter genotype (FW - strong Vrn sensitivity, insensitive Ppd) was best suited to early sowing in medium-low rainfall southern and western environments. The mean yield advantage of this type sown early was 0.5-0.7 t/ha compared with a fast developing spring genotype (FS - representative of contemporary Australian cultivars) sown mid-late May which is representative of current practice. In cooler, higher rainfall environments in SW Victoria and S NSW, a winter type with additional Ppd sensitivity (MW) was the highest yielding. In warm northern environments with summer dominant rainfall, there was no significant time of sowing by genotype interaction.

Key words
Yield, phenology, development, adaptation

Introduction

In the wheat growing regions of southern and Western Australia, late autumn rainfall has declined in recent decades (Cai *et al*., 2012; Pook *et al*., 2009), which has prevented the mid-fast developing wheat cultivars favoured in the region from being established at their optimal date. Late establishing wheat crops flower too late and are exposed to drought and heat stress which substantially reduces grain yield (Flohr *et al*., 2015). Farmers have responded to this challenge by retaining crop residues on the soil surface over summer and improving control of summer weeds to in order to improve storage and capture of summer rain (Hunt *et al*., 2013). This improved soil water storage combined with rain in late summer and early autumn (which has not declined in recent decades) provides an opportunity for growers to establish wheat crops much earlier than previously practiced, and remove reliance on April-May rainfall for timely crop establishment. Crops can easily be established on stored soil water using modern no-till farming techniques, and weeds and diseases of early-sown crops controlled with recent advances in pesticides. However when crops are sown earlier, the rate of cultivar development needs to be adjusted so that crops do not flower too early and become exposed to greater frost risk. Slower developing cultivars sown early have also been shown to produce higher grain yields than fast developing cultivars sown later that flower at the same time (Coventry *et al*., 1993; Hunt *et al*., 2012; Kirkegaard *et al*., 2014). A lack of contemporary slow developing cultivars is preventing growers implementing this practice. Over the last century Australian wheat breeders have focussed on cultivars with increasingly rapid development through selection of insensitive photoperiod (Ppd) and vernalisation (Vrn) alleles (Davidson *et al*., 1985; Eagles*et al*., 2009). There are few contemporary cultivars with appropriate developmental delays in flowering suitable for sowing early in autumn. The notable exceptions are several mid-developing winter wheat cultivars (EGA Wedgetail, Wylah, Whistler) bred by the NSW Department of Agriculture breeding program at Temora that closed in 2002.

In order for growers to take full advantage of sowing opportunities in early autumn, new cultivars are required that combine the necessary developmental alleles with updated disease resistance genes and other traits. In response to these issues, this study aimed to inform breeding programs as to what combinations of Vrn and Ppd sensitive alleles are best suited to early sowing in different production environments of the Australian wheat belt.

Methods

Near isogenic lines (NILs) that vary in alleles of major development genes governing Vrn and Ppd response were developed by crossing desired alleles into the recurrent parent Sunstate to backcross five. Four NILS were selected that varied in their response to Vrn and Ppd. This included a Ppd insensitive winter line (fast winter, FW), a moderately Ppd sensitive winter line (mid-winter, MW), a strongly Ppd sensitive spring line (very slow spring, VSS) and Ppd insensitive spring wheat control (fast spring, FS = Sunstate) which is representative of currently favoured cultivars (Table 1).

Table 1. Alleles of the major genes which govern response to vernalisation (Vrn; v=sensitive, a=insensitive) and photoperiod (Ppd; b=sensitive, a=insensitive) in the four near-isogenic lines.

	Photoperiod		Vernalisation		
Cultivar	Ppd-B1	Ppd-D1	Vrn-A1	Vrn-B1	Vrn-D1
Mid winter (MW)	*a*	*b*	*v*	*v*	*v*
Fast winter (FW)	*a*	*a*	*v*	*v*	*v*
Very slow spring (VSS)	*b*	*b*	*a*	*a*	*a*
Fast spring (Sunstate - FS)	*a*	*a*	*v*	*a*	*a*

The four NILs were sown in replicated split-plot experiments which included multiple sowing dates, at 14 locations across the Australian wheat belt from 2012 to 2014. Sowing times were chosen such that the last time of sowing was optimal in that environment for a fast developing spring cultivar and additional times of sowing occurred at ~14 day intervals prior to this. This gave consistent sowing times across sites in some regions (e.g. SA & WA), but not in others (e.g. QLD) where sowing times needed to be on different calendar dates in different locations in order to achieve the optimal flowering period in that environment. Small amounts of irrigation (5-10 mm) applied using pressure-compensating drip line were used to establish different times of sowing if soil was too dry to guarantee establishment. Sufficient synthetic fertilisers were applied such that nutrients did not limit yield, and weeds, diseases, insects and fungal pathogens were controlled with registered pesticides such that they did not limit yield. Anthesis date of different NILs were recorded at key sites, and grain yield measured by machine harvest. All yields are reported at field moisture content. Yields were analysed as multiple experiments within agro-climatic clusters using linear mixed models (REML) accessed via the GenStat 16 user interface with sowing date and line as fixed effects and site and block structure as random effects.

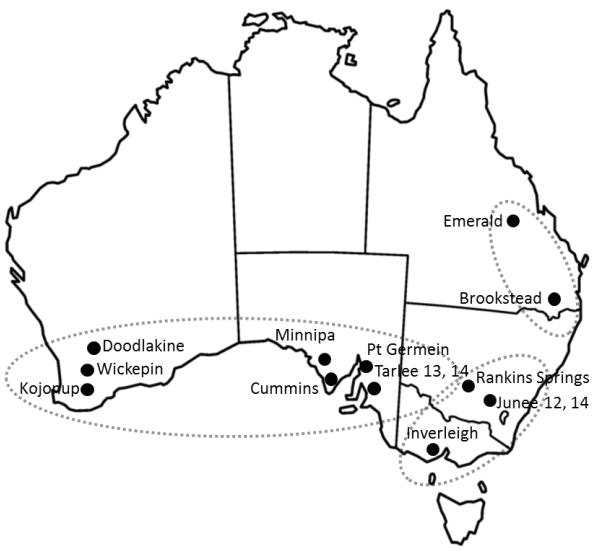


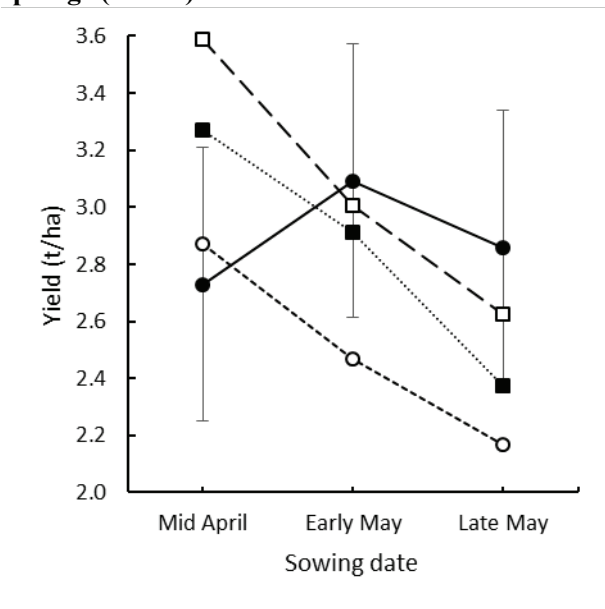
Figure 1. Experimental locations used in the study. Sites where more than one year of data has been collected are denoted with the last two digits of these years following the site name. Dotted lines define three different agro-climatic groupings (WA and SA sites with cool winters and hot springs, SW VIC and S NSW sites with cold winters and mild springs, QLD sites with mild winters) based on yield performance of NILs at early times of sowing.

Results

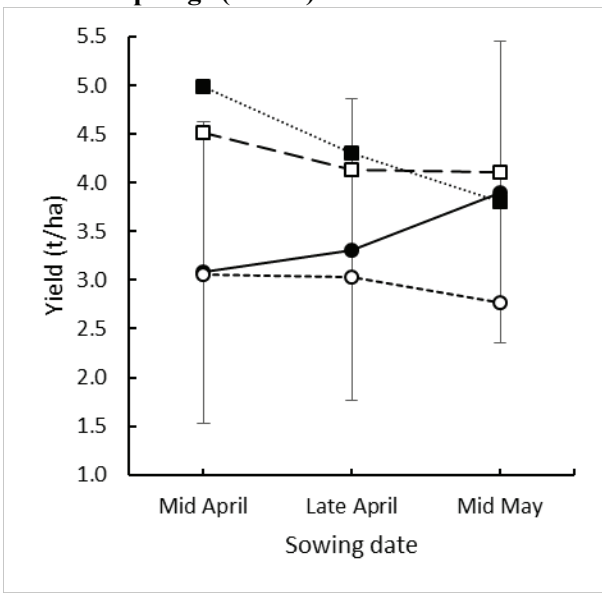
Sites were grouped according to which NIL yielded most at the first time of sowing. This gave three groups of sites which were geographically contiguous and agro-climatically sensible (Figure 1), and data reported herein are predicted mean yields from linear mixed model analysis of the different lines across multiple sites within each of the agro-climatic zones.

The largest group (8 sites) was comprised of sites in WA and SA that experience cool winters with hot, dry springs and typically have an optimal flowering period in the first half of September (Flohr *et al*., 2015). In these environments the FW line gave the highest yield at early (mid-April) times of sowing (Fig 2a). The mean yield advantage of FW sown mid-April over FS sown in early and late May (current practice) was 0.5 t/ha and 0.7 t/ha respectively (Figure 2a). Yields of the FW and FS lines were not significantly different when both were sown in early and late May. The MW line was too slow to flower in these environments and yields were reduced by terminal drought and heat stress. When sown early in all southern environments, the VSS line produced deformed, largely infertile spikes. This is possibly a response of the strong PPD sensitivity of this line when it initiates flowering under short days, and the same effect was not observed at the northern sites.

a) WA and SA sites with cool winters and hot springs (8 sites)



b) SW VIC and S NSW sites with cold winters and mild springs (4 sites)



c) QLD sites with mild winters (2 sites)

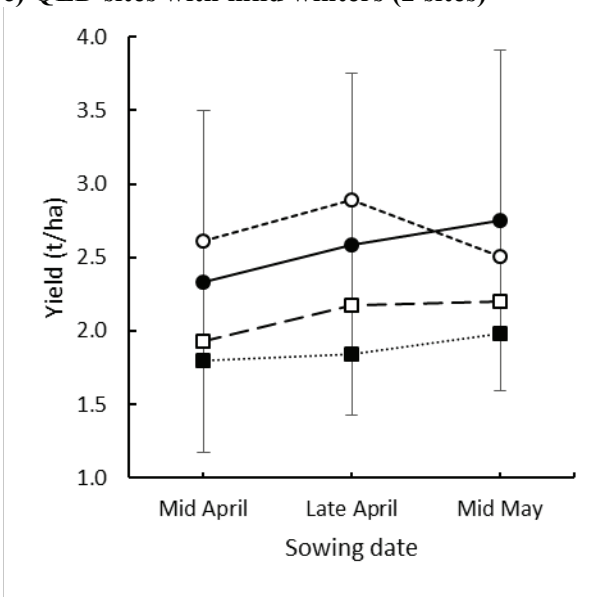


Figure 2. Yield of the NILs Fast Winter (□), Mid Winter (■), Very Slow Spring (○) Fast Spring (●) for the agroclimatic groupings in Figure 1. Error bars on Fast Spring values are +/- 2 x average standard error of the difference for the sowing date and genotype interaction from the linear mixed model analysis. Each error bar represents an approximate 5% least significant difference (LSD) for comparing all means. Error bars have only been added to the Fast Spring means to assist with clarity, as it is representative of current practice.

The second largest grouping (4 sites) comprised sites in S NSW and SW Victoria which experience cool winters and relatively mild springs and typically have an optimal flowering period from late September to mid-October. In these environments the highest yield treatment was the MW line sown in mid-April (Fig 2b). The mean yield advantage of MW over FS when both are sown in mid-April was 1.9 t/ha. However, the mean yield advantage of MW sown mid-April over FS sown mid-May (current practice) was not significant. This result supports the simulated study of Bell *et al*. (2015) who found significant yield advantage of winter wheats sown early in contrast to spring wheats sown later in these regions. The final grouping comprised the two QLD sites. When these sites were analysed individually there was a significant time of sowing x genotype interaction at each site, with the VSS line being highest or equal highest at the first two times of sowing (data not shown). However, when analysed together there was no significant ToS x genotype interaction due to small sample size and associated error (Fig 2c). At both of these sites, the winter lines were too slow to vernalise and flowered too late for stable yield (data not shown).

Conclusions

The results of this study demonstrate that when disease and nutrients were non-limiting, a significant yield advantage was associated with early sowing of slow developing NILs compared with later sowing of fast developing NILs in southern Australia. In order for growers to fully realise the benefits of early sowing in southern Australia, breeding programs are advised to develop FW and MW cultivars with good edaphic adaptation to these regions. Preliminary results from QLD environments with a relatively warm winter did not reveal significant yield advantages associated with earlier sowing of slower-developing NILs, although winter lines were unsuited to this environment and further investigation should focus on Ppd sensitive spring types. Additional experiments are being conducted in 2015 to further examine these trends in the Northern and South-Eastern agro-climatic zones where a smaller number of sites have been sampled.

Acknowledgements

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Floral initiation in maize is regulated by the growth of leaf primordia

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Abstract
Agronomists and plant scientists roughly calculate the timing of floral initiation in crops based on mathematical models of heat units (or thermal time) adjusted for day-length. To sanction this approach, there is dogma that plants have apparatuses or ways for measuring day-length and accumulating temperature, and intrinsic pathways between leaves and the shoot apical meristem for signalling the plant's developmental status. In this brief paper, we present data that describe the growth of maize leaf primordia in response to photoperiod treatments. The results show that the architecture of the shoot apical meristem is responsive to photoperiod and that a slow rate of leaf primordia elongation is coincident to tassel initiation.

Key words
Flowering, photoperiod, shoot apical meristem, tassel initiation, leaf elongation

Introduction
In two species, sorghum and maize, the timing of floral initiation was precisely synchronized with the slow elongation rate of leaf primordia (Ockerby *et al*., 2014; Yang *et al*., 2014). Measurement of the lengths of leaf primordia revealed that a consistent structure and function of the shoot apical meristem occurred just prior to floral initiation.

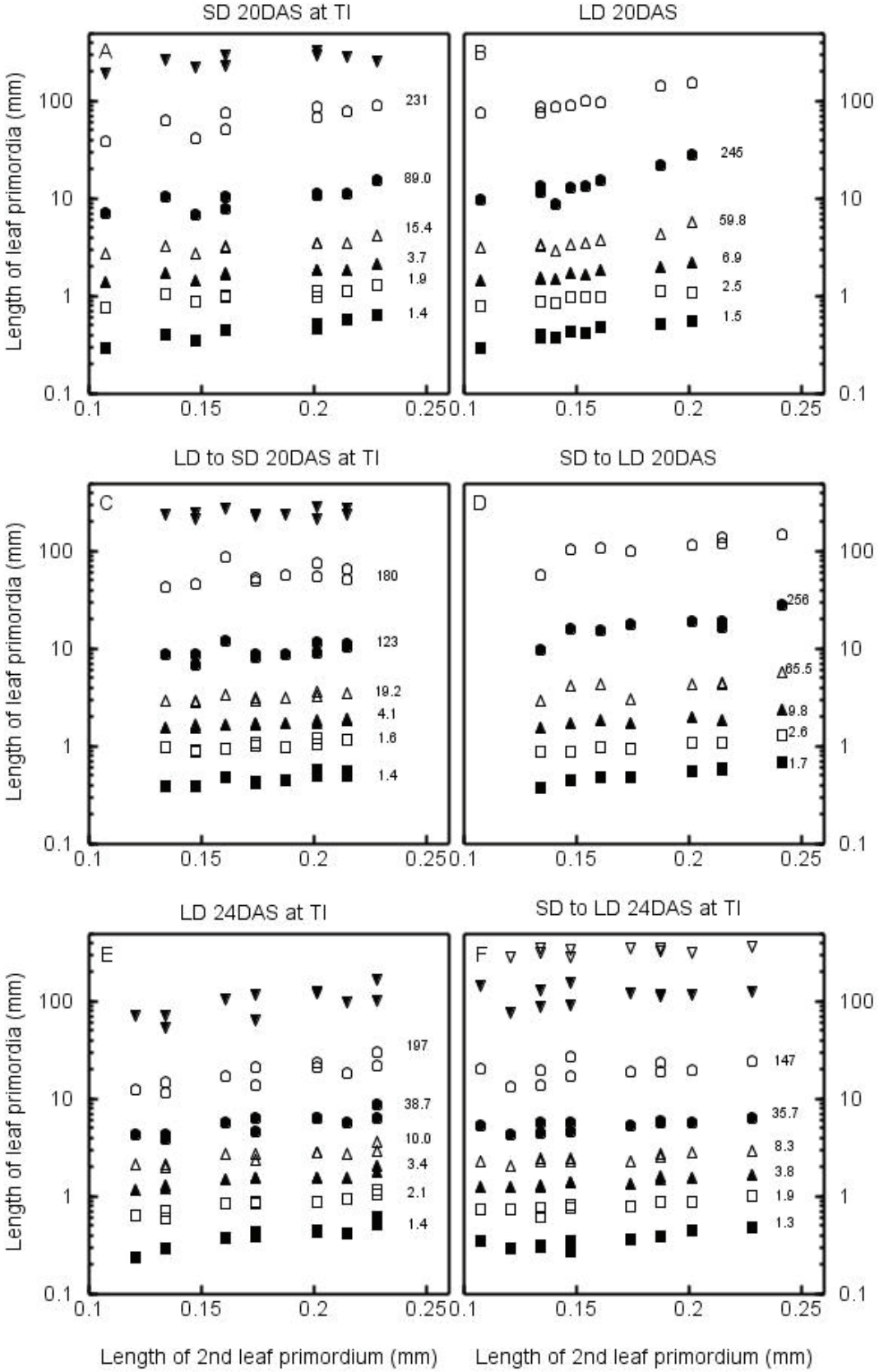
Methods
Maize (*Zea mays* L. cv. DK689) plants (eight per pot) were grown in several 15-L black plastic pots each containing 13.5 kg sandy clay loam soil (field capacity: 0.25 g g-1; permanent wilting point: 0.11 g g-1). Water and fertilizer were supplied as needed.

Two photoperiod treatments were imposed to observe their effect on the time of tassel initiation and the morphological characteristics of the shoot apical meristem. Plants in short days (SD) were given 9 h natural light at 30°C and 15 h darkness at 25°C, and plants in long days (LD) were given 9 h natural light at 30°C, 7 h low light from incandescent bulbs at 25°C and 8 h darkness at 25°C. Twelve days after sowing, half of the plants in LDs were transferred to SDs and half of the plants in SDs were transferred to LDs.

Plants were dissected under a microscope at frequent intervals (10-12 plants per treatments on each occasion usually every three days) to count leaves and measure the length of leaf primordia. Tassel initiation was scored when 70% of sampled plants had swelling at the base of the shoot apical meristem; (From Yang *et al*. 2014).

Results
When plants in SD and LD to SD had initiated a tassel, the plants in LD and SD to LD were vegetative and maintained faster rates of leaf primordia (LP) elongation (Fig. 1). Just 4 days later, the plants in LD and SD to LD initiated tassels but had also grown 2.6 extra leaves (17.8 cv. 15.2: $P<0.05$) with green leaf area of approximately 600 cv. 300 cm^2 and the elongation rate of LP had slowed to resemble (in a chronological-sense and numbered from the shoot apical meristem) those on SD and LD to SD plants at tassel initiation. Plants in LD and SD to LD had slightly shorter LP and slower rates of LP elongation at tassel initiation than those of SD and LD to SD plants, but the differences were much less than the changes within treatments in the 4d before tassel initiation. Plants that had been transferred from SD to LD and vice-versa responded to the condition in which they were in at the time of tassel initiation.

Fig 1: The lengths of leaf primordia (log scale) relative to the length of the second leaf primordium in vegetative maize (Zea mays) seedlings at 20 days after sowing (DAS) in (A) short days (SD), (B) long days (LD), (C) LD transferred to SD and (D) SD transferred to LD; and at 24DAS in (E) LD and (F) SD transferred to LD. Linear slopes of lines fitted to the untransformed data are shown for leaf primordium (■) 3, (□) 4, (▲) 5, (Δ) 6, (●) 7, (○) 8, and (▼) 9. Values of Y for each value on the X-axis represent the leaf lengths of a single plant. Tassel initiation (TI).



Discussion

The results were typical of those reported in our papers (Ockerby *et al*., 2014; Yang *et al*., 2014) for both sorghum and maize plants that were subjected to natural and artificial treatments: season, agronomy, light intensity, photoperiod, cultivar or defoliation; which resulted in variation in the both plant growth and the timing of floral initiation.

Slowing in the elongation of leaf primordia (LP) to critical thresholds may have engendered conditions in the shoot apical meristem that triggered the transition from the vegetative to the floral phase. The phenomenon would be consistent with the thesis of Turing (1953) in the sense that the expression of genes in a cell (to determine what a cell looks like and does) can be regulated locally by chemical substances called morphogens. In the current study, the growth of maize LP may just indicate the growth status of the shoot apical meristem, or it may reckon between the rate of producing new vegetative tissue (cell division) and the capability to expand or grow those cells; and either may be physiologically-constrained by the resource supplied or the environmental controls that regulate plant growth. Knowing how a plant responds and what causes it to differentiate different cell types at the shoot apical meristem will enhance our faculty to work with the conditions causing the development of yield-forming plant structures (Otegui and Slafer, 2004).

Conclusion

The recurring association between the elongation rate of leaf primordia and floral initiation under a range of conditions and treatments in two species (photo-period and maize discussed in this paper) should be cause for scientists to rethink how floral development is triggered.

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Effect of anthesis date on grain yield and yield components of wheat – Trangie 2009-2012

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Abstract
The response of a range of wheat varieties to sowing date was examined at Trangie Agricultural Research Centre from 2009-2012. Grain yield related strongly with both anthesis date and grain number m^{-2} in the drier seasons of 2009 and 2012. There was a weak to moderate relationship between grain yield and anthesis date in the more favorable seasons of 2010 and 2011, with a weak relationship between grain yield and grain number in 2011. There was a weak relationship between grain yield and individual grain weight in 2010 and 2012 only. Grain growers in the region have historically managed crops conservatively to limit stress during the post-anthesis grain fill period; however grain number (which is largely affected pre-anthesis) had a stronger relationship with grain yield than did grain weight, suggesting that management could focus more on minimising pre-anthesis stress.

Key words
Grain number, grain weight, sowing date, pre- and post-anthesis stress

Introduction
Wheat is the major winter grain crop planted in the Western Plains region of NSW, an area covering the shires of Narromine, Warren, Gilgandra, Coonamble and Bogan. The NSW Grains Report from October 2012 reports that wheat comprised 70% of the area planted to winter crops in that season. The soils of this region vary but are generally of moderate to high water holding capacity (from 100 to 300 mm plant available water). Although historical rainfall records show a summer dominant rainfall pattern, both inter and intra-seasonal rainfall can be highly variable. The farming systems of the region are based on storing out-of-season (November – March) rainfall in the soil, with crops then supplemented by winter rainfall. Crops are often managed conservatively (e.g. low seeding rates, low nutrition inputs, wide seeding rows) as there is a fear of drought occurring during grain fill which may lead to 'haying-off' and reduced grain size.

Sowing time decisions and varietal phenology both affect the wheat crops potential exposure to frost damage (declining risk from late winter) and heat stress (increasing risk from early spring). Sowing time decisions may also affect the partitioning of water use for pre and post-anthesis growth. Cooper (1992) reports an optimum anthesis date of 15 September for Trangie, beyond which grain yield decreases due more to increased temperature than moisture stress.

Experiments were conducted at Trangie Agricultural Research Centre from 2009 to 2012 to determine the response of a range of wheat varieties to 3-4 sowing dates, including dates that are considered 'early' (late April – early May), 'main' (mid-May) and 'late' (June). This paper reports on the findings in terms of the effect of anthesis date and yield components on final yield outcomes.

Methods
Wheat time of sowing experiments were conducted over four seasons (2009-2012) at Trangie Agricultural Research Centre (31.99ºS, 147.95ºE) on a grey vertosol soil with a water holding capacity of 183 mm. This location experiences a temperate to sub-tropical climate, with hot summers, mild winters and summer dominant rainfall (Figure 1). Experiments were sown as a split-plot design, with sowing date as the main plot and varieties as sub-plots. Treatments were replicated three times. All experiments were managed for optimised nutrition and to limit the effects of pests and diseases. Sowing dates were similar across seasons (Table 1) but varieties differed from season to season, with five varieties (Crusader, EGA Gregory, Livingston, Sunvale, Sunzell) sown in each season. Anthesis date was recorded as the date where 50% of

ears had yellow anthers (on a whole plot basis). Grain yield (GY) was based on machine harvest, with grain analysis completed on these machine harvested samples. Grain number m^{-2} (GN) was calculated from GY and one hundred grain weight (GW) of each treatment.

Table 1: Sowing dates, number of varieties in each trial, plant available water (PAW) at sowing and rainfall from soil water coring to maturity (in-crop rain) in four wheat variety by sowing date experiments at Trangie Agricultural Research Centre from 2009 to 2012.

Season	Sowing dates	No. of varieties	PAW mm (sow)	In-crop rain (mm)
2009	27 Apr, 18 May, 12 June	36	76	168
2010	20 Apr, 3 May, 19 May, 10 June	18	174	363
2011	30 Apr, 16 May, 9 June	18	178	230
2012	3 May, 21 May, 12 June	15	171	127

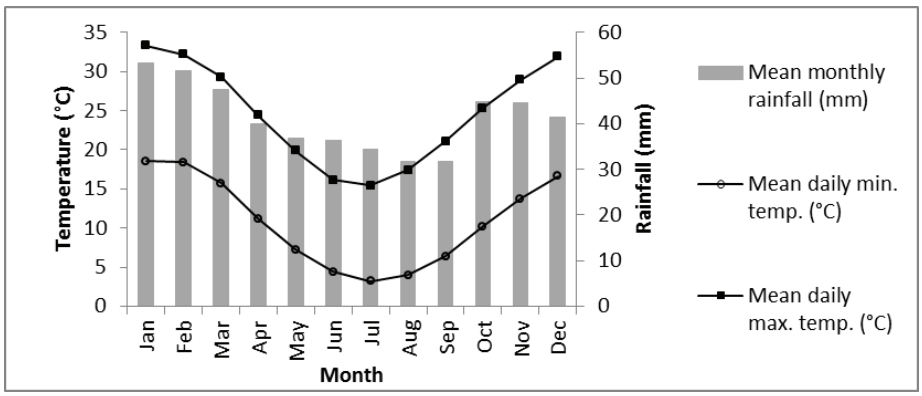

Figure 1: Average (1922-2014) climatic conditions for Trangie Agricultural Research Centre, NSW.

Results and discussion

The experiments in the seasons 2010-2012 were all sown into a near full soil moisture profile (Table 1). In comparison, the soil moisture profile in 2009 was approximately 100 mm less. In-crop rainfall ranged from very low in 2012, low in 2009, average in 2011 to well above average in 2010. The overall temperature through the growing season was well above average in 2009 but close to average for 2010 to 2012.

Due to the very warm late-winter and spring conditions (both minimum and maximum temperatures) in 2009 the treatments that reached anthesis early (from mid-August) had the highest GY. From this point GY was negatively related to anthesis date (Figure 2).
The relationship between anthesis date and GY was curvelinear in 2010-2012 (Figure 2), with a stronger effect of anthesis date on GY in the drier year of 2012. There were a number of late winter and early spring frosts recorded in 2012 that potentially reduced GY of the early flowering treatments; however in 2010 and 2011 there were no major frost events recorded. In 2010 and 2011 the treatments that reached anthesis early were likely unable to make full use of the resources available in those favourable seasons. The optimum anthesis dates were similar for the seasons 2010-2012 (about 12 September).

Over the experimental period, the rate of GY decline after the optimum anthesis date ranged from a low of 33 kg ha.day^{-1} in 2011 to a high of 57 kg ha.day^{-1} in 2012. The average GY reduction over the four seasons after the optimum anthesis date was 1.1% day^{-1}, which is similar to the 1.3% day^{-1} reported by Cooper (1992) from experiments conducted at the same location.

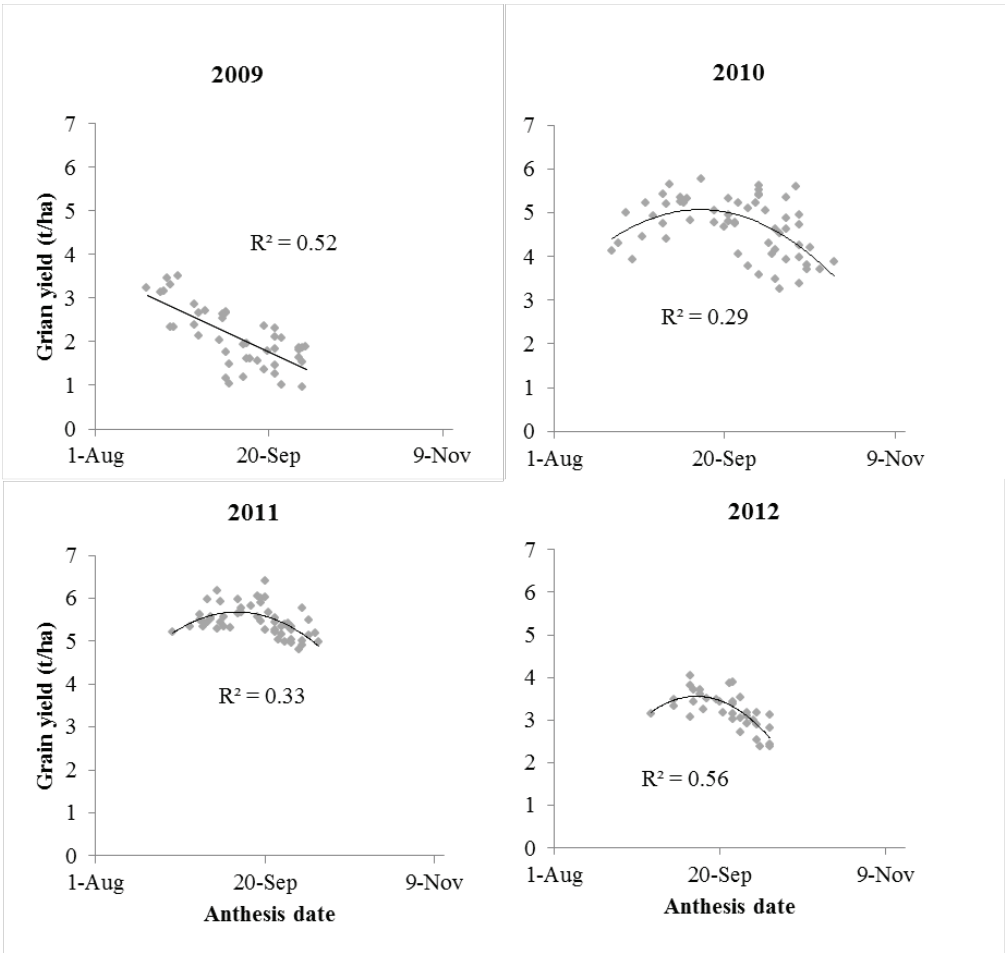

Figure 2: Regression of anthesis date and grain yield was significant (p<0.001) in wheat variety by time of sowing experiments from 2009 to 2012 at Trangie Agricultural Research Centre. The relationship was strongest in the drier years 2009 and 2012.

There were strong positive relationships between grain number (GN) and GY in the drier seasons of 2009 (R^2 = 0.91) and 2012 (R^2 = 0.66). There was a weaker relationship in the 'average' season of 2011 (R^2 = 0.25) and no significant relationship in the very wet season of 2010 (Figure 3). A regression of individual grain weight (GW) with GY was also completed for each season. The regression was significant (but weak) only in the seasons 2010 (R^2 = 0.08) and 2012 (R^2 = 0.30).

Fischer (2011) reports that final GN of wheat is most affected by stress in the period leading up to anthesis, while GW is more affected by conditions post anthesis. In these experiments the relationship between GN and GY was overall stronger than the relationship between GW and GY, suggesting that stress pre-anthesis was affecting grain yield more than stress post-anthesis. Importantly, it was in the drier years of 2009 and 2012 where GN related to final GY most strongly. It has been for these types of drier years that conservative agronomic practices have been implemented; however this research would suggest that conserving resources for the grain fill period may not lead to positive grain yield outcomes (though there may be implications for grain marketing).

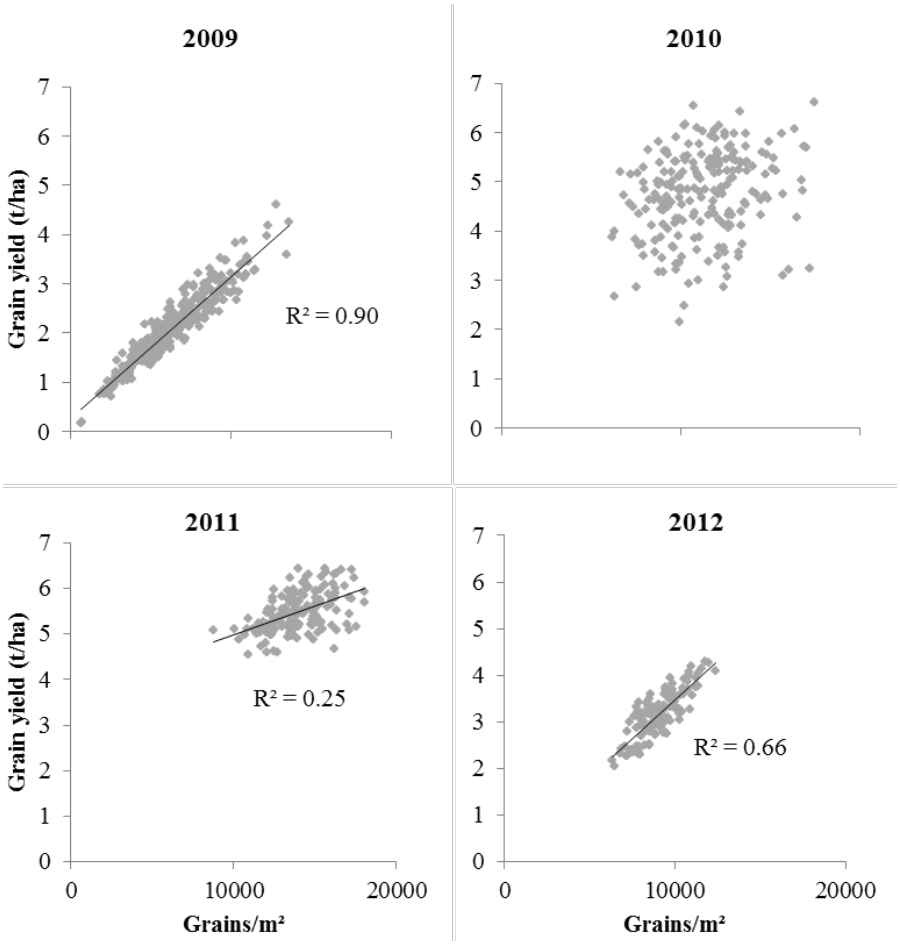

Figure 3: Regression of grain number (grains/m^2) and grain yield of wheat in variety by time of sowing experiments from 2009 to 2012 at Trangie Agricultural Research Centre was significant in all experiments ($p<0.001$) with the exception of 2010. The relationship was strongest in the drier years 2009 and 2012.

Conclusions

Wheat growers in the Western Plains region of NSW have historically managed crops conservatively, the aim being to limit the amount of stress on the crop during the grain filling phase, especially in dry years. Taking the two drier years of 2009 and 2012 in this research as an example, the efforts of these growers may be counter-productive, as it was the drier years where GN most strongly related to GY. Only in one of these drier seasons (2012) did GW have a significant effect on grain yield.

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Can the duration of the spike construction phase increase the yield of wheat?

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Abstract
It is proposed that increasing the duration of the spike construction phase (CPD, i.e. beginning of stem elongation to flowering) of wheat to increase the number and size of grains per m^2 will significantly increase grain yield in the High Rainfall Zones (HRZ). Field experiments undertaken in Canberra, Hamilton and Hobart in 2012, demonstrated genotypic variation in CPD in the CSIRO wheat Multiparent Advanced Generation Inter Cross (MAGIC) population compared with check cultivars. Variation in CPD was determined as the difference between dates of terminal spikelet (determined by microscopic dissection) and flowering and ranged from 309 to 950 °Cd (base (Tb) = 0°C). Height of the ligule relative to the apex was investigated as a possible technique for easily estimating terminal spikelet without the need for microscopic dissection, but the results were inconclusive. This project has now entered its next phase with the testing of fifty lines selected from the MAGIC population, at multiple sites, together with commercial and near-isogenic wheat lines differing in vernalisation and photoperiod alleles. The sites used were Canberra, Hamilton, Cressy and at two sites in WA (Badgingarra and Kojonup) for up to two sowing dates (April, May) and were assessed for CPD and grain yield in 2014. These site locations were chosen to provide a range of sites that vary both in climatic and day length variation across the growing season. Implications for breeding a new ideotype of wheat for the HRZ are discussed.

Key words
Phenology, high rainfall zone, genotypic variation, terminal spikelet, construction phase duration

Introduction

Modelling studies indicate that the High Rainfall Zone (HRZ) of southern Australia has high yield potential but that this potential is not being realised (Zhang *et al*. 2006; Sylvester-Bradley *et al*. 2012). To identify important traits for wheat to maximise resource capture and partitioning into grain, an 'ideotype' was proposed specifically for the HRZ of southern Australia (Sylvester-Bradley *et al*. 2012). Traits relating to crop development (phenology) were identified as being of particular importance in defining the ideotype (Figure 1).

Phenology is considered the single most important factor for adaptation and maximising grain yield as it controls the timing of critical growth stages, which are affected by abiotic stresses and influence the partitioning of photosynthate (Richards 1992; Gomez-Macpherson and Richards 1995). Important phases within the life cycle of a crop include the vegetative or foundation phase (GS00 to GS31/terminal spike), stem extension or construction phase (GS31/terminal spike to GS65) and the grain fill phase (GS65 to GS 91). The ideotype identified an optimum foundation phase duration of 650°Cd (base (Tb) = 0°C) that is considered sufficient to produce enough tillers to survive to produce 400-500 ears/m^2 at harvest. It also identified the need for a longer construction phase duration (CPD) (i.e. 800-1,200°Cd, Tb = 0°C) to delay flowering beyond the period of high frost risk and to provide time to increase the carbon supply to the developing ear so as to increase grain number. A duration of 700°Cd (Tb = 0°C) was identified for grain fill.

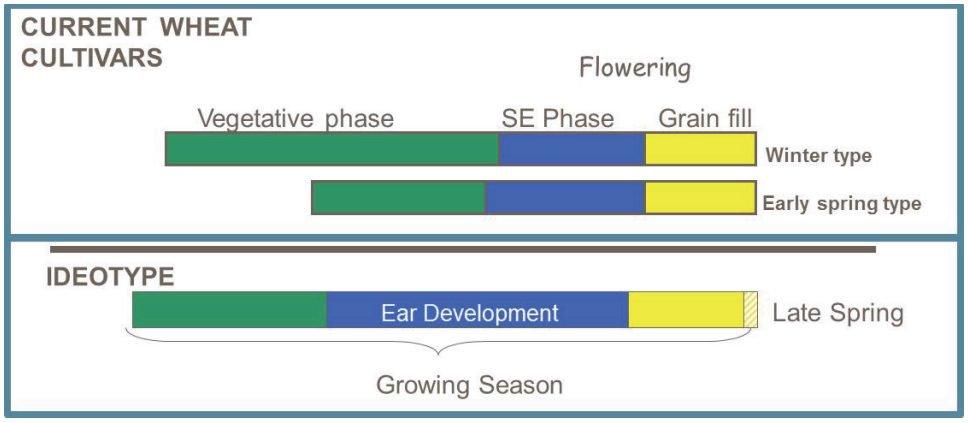

Figure 1. Differences in phase durations for current winter and spring wheat types and the crop ideotype proposed by Sylvester-Bradley *et al.* (2012). SE is stem extension or construction phase.

A lengthening of the CPD has also been identified as a means of increasing yields in other studies. Miralles *et al*. (2000) provided evidence that a longer construction phase increases floret fertility and grain number, which is associated with increased grain yield in temperate cereals (Miralles et al. 2000; Reynolds *et al*. 2005). Reynolds *et al*. (2005) showed that wheat lines containing the alien translocation 7DL.7Ag to have increase grains per m^2 (15%), grain yield (12%) and biomass (9%) compared with control lines. This was associated with 15% more spike biomass at anthesis and 10% more grains per spike. Furthermore, an increase in the amount of assimilates allocated to the spikes in semi-dwarf wheats led to an increase in partitioning to the spike relative to the stem which resulted in improved HI and grain yields (Syme 1970; Fischer and Stockman 1986).

The experiments reported here were undertaken in Canberra, Hamilton and Hobart in 2012 to determine if there was genotypic variation in construction phase duration in the CSIRO wheat Multiparent Advanced Generation Inter Cross (MAGIC) population (Canvanagh *et al*. 2008). In addition, accurate measurement of terminal spikelet typically requires microscopic dissection of the apex, which is not well suited to mass screening of this trait in a breeding population. Consequently, height of the ligule of the youngest fully-expanded leaf was also investigated for potential use as indicator of apical development.

Methods

To test the effects of a longer CPD on grain yield and yield components in the HRZ, MAGIC lines were selected so that when sown on the same date lines would have a similar flowering time but differ in the timing of terminal spike. More than four hundred lines together with eight check varieties were sown in single rows at three locations (Canberra, Hamilton and Hobart) on 7 June 2012 and dates to terminal spike and flowering were recorded. Terminal spikelet was assessed through microscopic dissection with the date deemed to be when the majority of five plants collected from the same day were at TS. The height of the apex and to the ligule of the youngest fully-expanded leaf was also recorded. Date of flowering (GS65) was recorded as when the anthers from mid spike are visible in 50% of main stems in the plot. Mean temperature data was used to determine the thermal time of phase durations at Tb=0°C.

Results

Determination of the CPD required the identification of key stages of development, including terminal spikelet and anthesis. We investigated whether height of the ligule of the youngest fully-expanded leaf could be used as an indicator of apical development. The purpose of this investigation was aimed improving the time efficiency of screening lines for terminal spikelet date. The length of the apex increases as it transitions from the production of leaf to spikelet primordia, culminating in terminal spikelet (data not shown). The height to the ligule of the youngest fully expanded leaf was correlated with the length of the apex (Figure 2). However, there was no relationship between height to the ligule and stage of apical development on a scale from 1 (vegetative) to 8 (reproductive), where 5 was terminal spikelet (Figure 2). Consequently, accurate determination of the date of terminal spikelet (TS) will continue to rely on microscopic dissection of the apex, which has implications for the efficiency of screening for this trait in a breeding program.

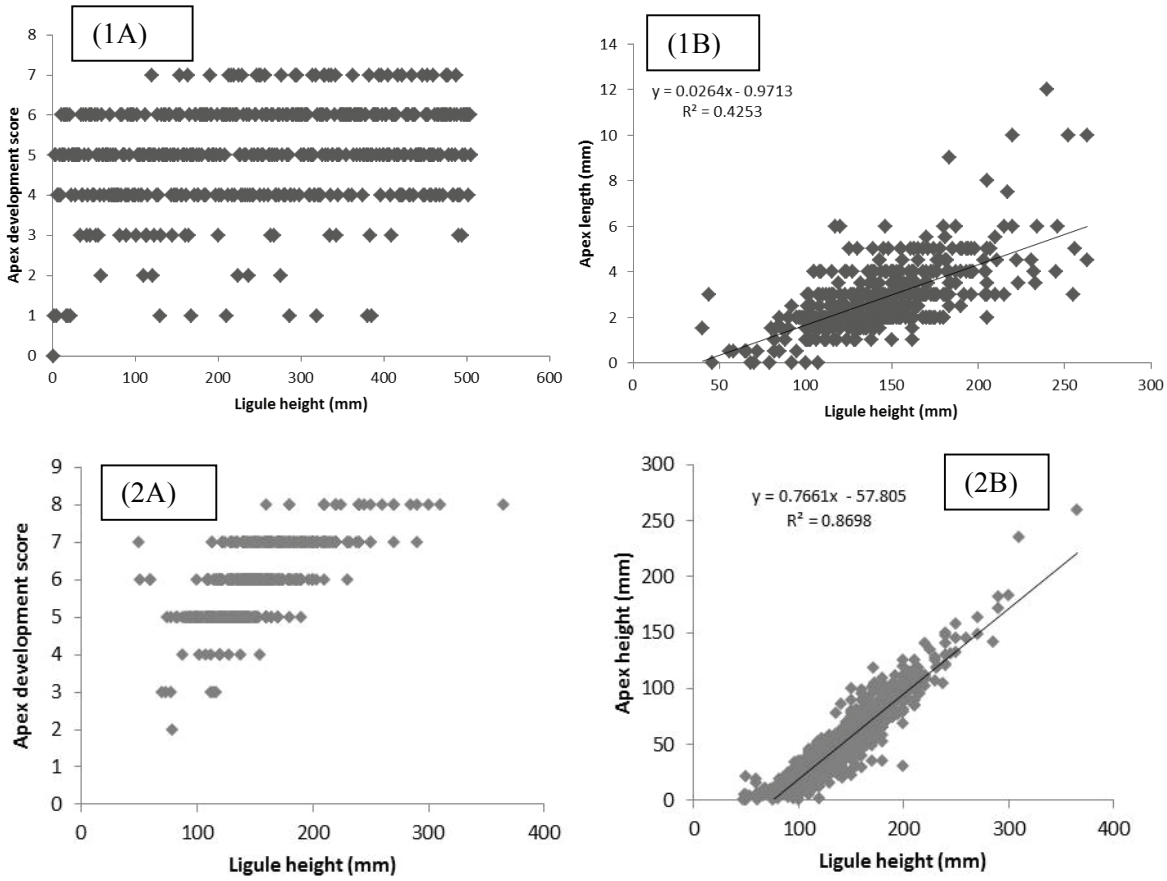

Figure 2. Relationship between stage of development of the apex, where 1 = vegetative and 5 = terminal spikelet with ligule height (A); and (B) ligule height and length of the apex. Data is from Hobart (1) and Hamilton (2), 2012. Data for Canberra is not reported.

Construction phase duration varied from 309 °Cd (in Canberra) to 1150 °Cd in Hobart (Figure 3). The check cultivar, Preston, had a relatively short CPD of 626 °Cd (Hobart), 614 °Cd (Hamilton) and 511 °Cd (Canberra), while Brennan was 1007, 626 and 658 °Cd for Hobart, Hamilton and Canberra, respectively, consistent with their maturity types. There was considerable variation in ranking between lines with the shortest and longest CPD across sites, potentially indicating a large genotype x environment interaction for this trait.

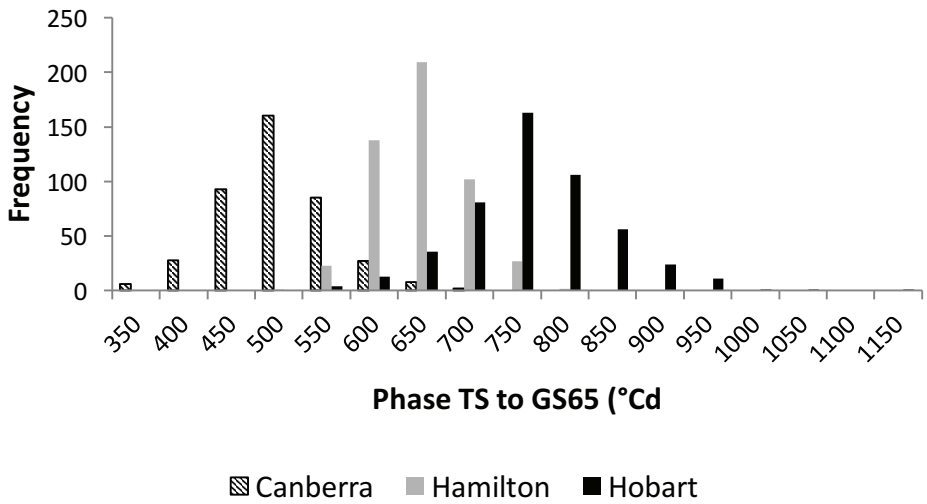

Figure 3. Frequency of lines varying in construction phase duration (terminal spikelet to anthesis, GS65). Data is from Hobart, Canberra and Hamilton in 2012.

Conclusion

Importantly, this work has confirmed using a large population of lines that genetic variation does exist for the length of the construction phase duration (CPD) needed to achieve the proposed ideotype of Sylvester-Bradley *et al*. (2012). Together with known information on the photoperiod and vernalisation genes involved, this should improve the ability to predict phenology in new lines across different environments. Attempts to identify a simple measurement of apex development, and hence terminal spikelet, were unsuccessful. Consequently, accurate determination of terminal spikelet will continue to rely on microscopic dissection. Although time-consuming, this level of detail in collecting data is necessary so to have confidence in reported variation in CPD.

In 2012 there was only sufficient seed to sow single rows in these preliminary experiments, so no yield data (per unit area) was measured. The relationship between an increase in the CPD and associated increase in the number of grains per spike and grain yield is being validated in the next phase of the project. The measured CPD across the three sites in 2012 was used to select the ranges of lines suited for testing in Tasmania, Victoria, ACT and Western Australia. We intend to quantify the contribution of genotype x environment interactions to CPD in this phase of the research. It is expected that within the life of the project breeders will have the capacity to incorporate different combinations of photoperiod and vernalisation genes into new germplasm specifically targeting the HRZ.

Acknowledgements

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Phenotypic plasticity of grain yield in oat and its association with agronomic and phenological traits

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Abstract

Oat production in Australia needs to expand into new, low rainfall regions to meet increasing domestic and international demand for both grain and hay. The objectives of this study were to (i) quantify and compare grain yield plasticity of oat entries in contrasting environments; (ii) relate yield plasticity with yield under favourable (90th percentile) and stressful conditions (10th percentile); (iii) study the associations between yield, agronomic and phenological traits. Variance ratio as a measure of yield plasticity was quantified for 29 entries in nine environments resulting from the combination of locations and seasons. Entries included advanced breeding lines, released varieties of grain, hay and grazing types which vary in yield, height, growth habit and maturity.

Yield was affected by all three sources of variation: environment, genotype and their interaction (all $P<0.0001$). Yield plasticity ranged from 0.26 to 1.38 and correlated with 90th percentile yield, ranging from 2.3 to 5.5 t ha^{-1} ($R^2=0.78$; $P<0.0001$) and 10th percentile yield, ranging from 0.1 to 1.0 t ha^{-1} ($R^2=0.30$; $P=0.0096$). Residual analysis revealed that varieties with GS60 (anthesis) <1430 ^{o}Cd (base temperature = 0℃) were above average in both high and low yielding conditions. Grain varieties out yielded grazing and hay varieties. Plant height was significantly influenced by all the sources of variation ($P<0.0001$). Plasticity of height ranged from 0.43 to 1.64 and correlated with 90th percentile ($R^2=0.57$; $P<0.0001$). Average plant height across the environments ranged from 45 to 99 cm and non-linearly correlated with yield. Plasticity of plant height negatively correlated with yield plasticity.

Key words

Yield potential, stress, plant height, phenology, anthesis

Introduction

Oat production in Australia in 2012-13 was 1.12 million tonnes cultivated in 0.7 million ha (ABARES 2014) which returned an export earnings of $54 million. Oats are widely recognised worldwide for its nutritional and health benefits. Oat production needs to expand into new, low rainfall regions to meet increasing domestic and international demand for both grain and hay (AEGIC 2014) . Hence the importance of improving oat adaptation to water limited environments with no trade-offs in favourable conditions. The objectives of this study were to (i) quantify and compare grain yield plasticity of oat entries in response to contrasting environments; (ii) relate yield plasticity with yield under favourable and stressful conditions (Sadras and Richards 2014); and (iii) study the associations between yield, plant height, and phenology.

Materials and methods

Twenty nine oat entries were evaluated over three crop seasons (2012 to 2014) in four locations, Pinery, Riverton, Turretfield and Waikerie in South Australia. The entries consisted of advanced breeding lines, released varieties of grain, hay and grazing types which varied in yield, height, growth habit and maturity. Trials were sown in randomised complete block designs with three replicates. Plot size was 4.16m^2 (3.2 m x 1.3 m) and seeding rate was 165 seeds /m2 in Pinery, Riverton and Turretfield. Plot size was 7.2 m^2 (5 m x 1.44 m) and seeding rate was 180 seeds /m^2 in Waikerie. Crops were fertilized with 120kg ha^{-1} of diammonium phosphate. All other agronomic practices were in accordance to the specific requirements of each environment. Phenology was monitored weekly using the scale of Zadoks in Pinery and Riverton in 2013 and 2014. The time of stem elongation (GS31), anthesis (GS60) and hay cutting (GS71) was estimated and expressed as thermal time (^{o}Cd) calculated with a base temperature of 0°C. Meteorological data from the nearest station from Australian Bureau of Meteorology were used. Plant height was measured in four environments Pinery 2012, Waikerie 2012, Pinery 2014 and Riverton 2014 as an average of three observations per plot at physiological maturity. Yield was measured by machine harvesting the whole plot and expressed at 12% moisture content.

Variance ratio, as a measure of trait plasticity, was calculated as a ratio of the variance of the trait for each entry to the overall phenotypic variance of all the entries (Dingemanse, Kazem et al. 2010). Yield plasticity was related to the yield in low (10th percentile) and high (90th percentile) yielding environments (Sadras and Richards 2014). Regression analysis and analysis of residuals was used to study the association between traits and their plasticities.

Results and discussion

Riverton 2013 registered the highest (365 mm) and Waikerie 2012 the lowest (75 mm) rainfall from sowing to harvest. The difference between the evaporative demand and rainfall was the highest for Waikerie 2012 (411 mm) and lowest for Riverton 2013 (263 mm).

Yield was influenced by all three sources of variation environment, genotype and their interaction ($P<0.0001$). The environmental mean yield ranged from 0.3 t ha^{-1} to 4.4 t ha^{-1}. The top yielding lines averaged approximately 3.3 t ha^{-1} across environments (05302-19, Dunnart, Bannister) and the lowest yielding lines were Forester (0.98 t ha^{-1}), Riel (1.15 t ha^{-1}) and Tammar (1.97 t ha^{-1}).

Yield plasticity ranged from 0.26 to 1.38 and correlated strongly with 90th percentile yield and weakly with 10th percentile yield (Figure 1A). This means genotypes were similar in performance under stress (10th percentile) but varied in their potential in the favourable environment (90th percentile). Residual analysis for yield at 90th percentile returned significant differences ($P=0.003$) between grain varieties producing above average yields (red symbols Figure 1A) and hay or grazing varieties producing below average yield (green and blue symbols Figure 1A) for a given plasticity.

ANOVA returned significant differences in thermal time from sowing to GS31, GS60 and GS71 among entries ($P<0.0001$) but not for environment or interaction. Breeder lines were as early as 830 °Cd for GS31 (05089-31), 1301 °Cd for GS60 (05140-3) and 1412 °Cd for GS71 (05014-22). Grazing (MA lines) and hay varieties (particularly Forester, Riel, Tammar, Tungoo and Wintaroo) took longer to reach GS31, GS60 and GS71.

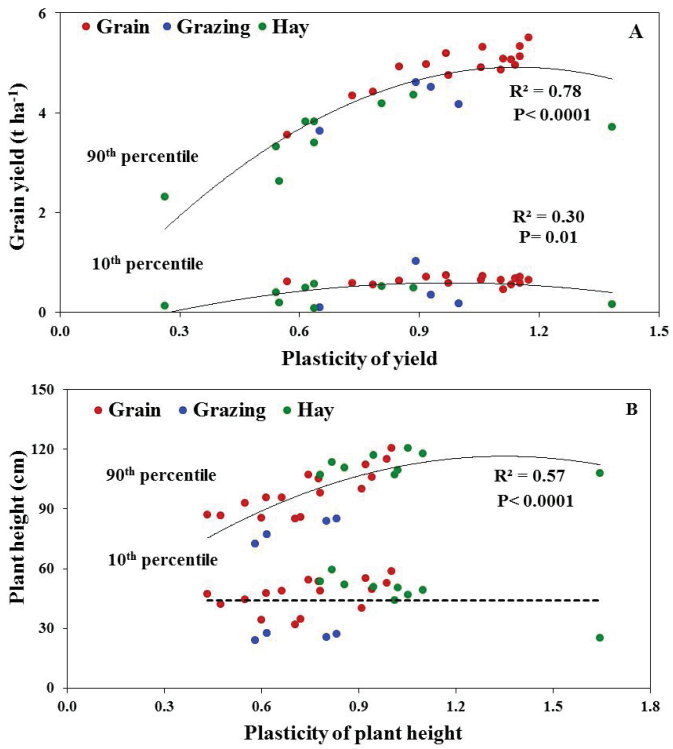

Figure 1. Relationship between (A) yield and yield plasticity and (B) height and height plasticity of 29 oat entries under favourable (90th percentile) and stressful (10th percentile) conditions.

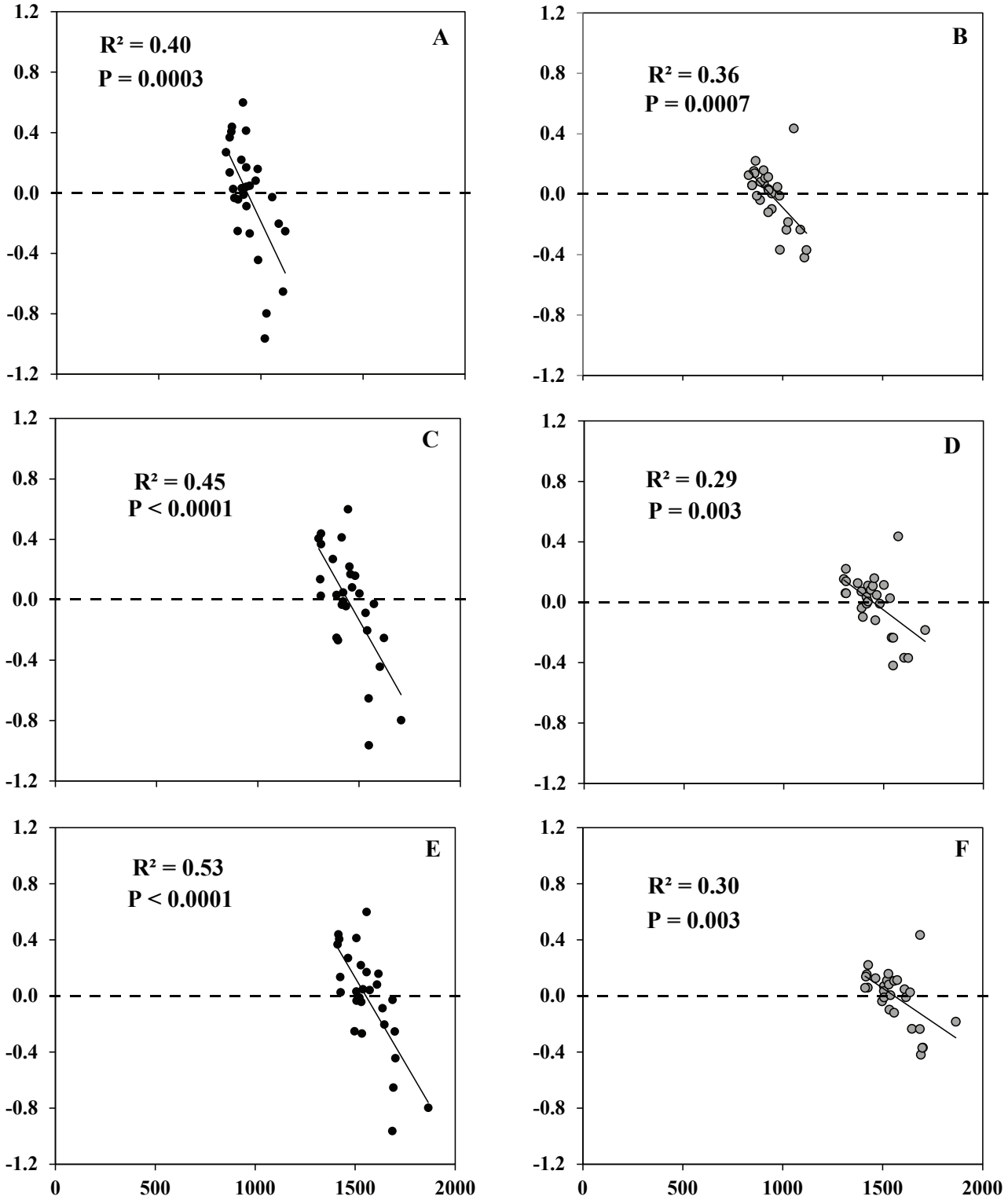

Figure 2 Relationships between residuals of yield vs plasticity at favourable (90th percentile) and stressful (10th percentile) environments of 28 entry's thermal time from sowing to GS31 (A & B), GS60 (C & D) and GS71 (E & F). Forester, an extremely late variety (1024 °Cd for GS31, 1923 °Cd for GS60 and 2032°Cd for GS71) was excluded from the analysis.

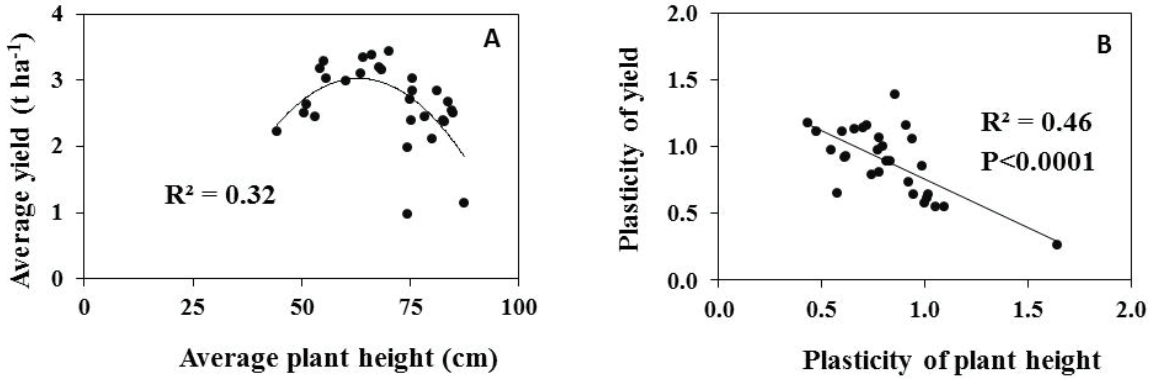

Figure 3. Association between (A) average grain yield and plant height and (B) Plasticity of grain yield and plasticity of plant height of 29 oat entries across the environments

Yield residuals at both favourable and stressful conditions correlated with thermal time to GS31, GS60 and GS71 (Figure 2). The relationship showed that the varieties, which attained GS31earlier than 949°Cd, GS60 earlier than 1430 °Cd and GS71 earlier than 1576 °Cd, contributed above average yields under favourable environment. Similar relationships, with similar thresholds, were found for yield under stressful conditions.

Plant height was influenced by all three sources of variation (P<0.0001). Average plant height across environments ranged from 45 to 99 cm. Plasticity of plant height ranged from 0.43 to 1.64 and correlated with 90th but not with 10th percentile plant height (Figure 1B). This means plasticity resulted from responsiveness to favourable conditions with no systematic variation among lines under stress. Average yield was non-linearly related to plant height and there was a negative relationship between plasticity of yield and plasticity of height (Figure 3A & 3B). Analysis of plant height is vital in breeding as this trait influences harvest index and yield (Figure 3B) with dwarf genotypes possessing greater yield potential than the tall genotypes. However, the tall genotypes have greater potential for hay yield.

Conclusion

Yield plasticity was mostly associated with yield under favourable conditions with no apparent trade-off between potential yield and yield under stress for the collection of entries and environments in this study. Early lines (GS60 < 1430 °Cd) yielded more than their late counterparts at the same plasticity. The relationships between yield and plant height need further study as plant height was confounded with growth habit. The association between plasticity of yield and plasticity of height is interesting and deserves further research.

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Simulated wheat phenology is improved when local temperature is used

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Abstract

Grain yield is affected by the timing of environmental stress. An accurate phenological model is important for simulations of yield and management procedures. Phenological models rely, in part or completely, on the accumulation of heat; thus if temperature is measured more accurately then the accuracy that phenology is simulated should be improved. Wheat (cv Gladuis and Axe) was grown in large well irrigated pots at six locations across a transect from Adelaide to Orroroo. Local temperature was monitored using Tinytag dataloggers at 1.2 m height. Phenology was assessed from sowing until early grain fill using destructive sampling and timelapse photography. The observed phenology was compared to phenology simulated by APSIM using either local temperature or regional (SILO) temperature. Local daily maximum and minimum temperature differed from that obtained from the Patched Point Data climate files from SILO. Simulated phenology more closely match observed phenology when local temperature was used compared to when regional temperature was used. This suggests temperature data input to the phenology model can contribute to errors in simulated phenology, and that locally measured temperature data performed more accurately than regional data. This then implies inputs of more accurate temperature data into the model would lead to improved accuracy of not only simulated phenology but also yield and would therefore allow greater understanding of the risks to production as a consequence of management practices or impacts of weather and climate.

Key words

Wheat, phenology, flowering, temperature

Introduction

Projected future climate for South Australia's cropping region indicate a warmer and potentially drier future. Projections from global circulation models (GCMs) and recent historical observations indicate daily minimum temperatures are increasing more than daily maximum temperatures, such that the diurnal temperature range has declined as the daily mean temperature has increased (e.g. Brazagna *et a*l. 2003). Such a climate is likely to affect the agronomy, yield and risk of exposure to adverse weather conditions at sensitive stages of crop development.

Simulation models such as APSIM (Agricultural production Systems Simulator) have been used to compare production under historic and projected future climates. A requirement of a robust agronomic simulation model is a well-developed phenological model, and provision of accurate climate data (most importantly temperature data for wheat phenology until the completion of flowering as other phenological drivers such as photoperiod can be calculated with high accuracy). Temperature data used in simulation modelling is usually obtained for a local meteorological station as observed data or interpolated data, but there will always be a difference between the meteorological station and the paddock. The first objective was to characterise the error in simulating wheat phenology when using temperature data obtained from a meteorological station compared to when using temperature measurements collected in the field where the wheat was grown.

An approach to evaluate the performance of the agronomic model under future warmer climates is to examine locations that differ in current climate, and use spatial analogues, or space as a proxy for time, to examine projected future climate change. By examining an already hot location an indication of what a cooler location may evolve into in a future warmer climate will be obtained. This approach has a long standing in ecological studies and more recently in agricultural systems. However, different locations rarely differ only in daily mean temperature and/or daily diurnal temperature range so that useful comparisons cannot always be made. This is especially the case in South Australia where sites closer to the coast have a much more narrow diurnal range than inland sites. It is therefore important that the simulation model can provide accurate simulations of phenology in these conditions. Phenological development of wheat is related

to daily mean temperature, but the effect of daily diurnal temperature range on the phenological development of wheat has been questioned. For example Slafer and Rawson (1995) show phenology is independent of daily diurnal temperature range while Chauhan *et al*. (2005) provide contrasting evidence when using similar daily mean temperature (19°C in Slafer and Rawson, 1995, 18°C in Chauhan et al., 2005) and daily diurnal temperature range (0 to 14°C in Slafer and Rawson, 1995; and 0 to 12°C in Chauhan *et al*., 2005). An additional objective of this research was to establish if phenology of wheat is affected by the daily diurnal temperature range independently of mean temperature and if the vernalisation - photoperiod and thermal time model used by APSIM accurately predicted phenology of wheat under these conditions.

Methods

Phenology data can be collected by careful observation of farmer's paddocks or trial sites such as NVT (National Variety Trials). A challenge of studying phenology across a transect is variation in emergence due to differences in both soil type and climate (autumn rainfall and temperature) across sites.

A field experiment in 2011 involved sowing cv Axe and cv Gladius at Roseworthy (34.52°S, 138.68°E, 47m ASL) and Waite Institute (34.97°S, 138.97°E, 103m ASL) on 30th June. Plants were harvested periodically and assessed for phenological development using the Zadok scale. At each site a temperature datalogger (Tinytag plus2 TGP-4500) was positioned at 1.2m height. The dataloggers were placed in radiation shields consisting of eight circular plastic rings of which two were solid enclosures and the remaining six formed an internal cavity of 8 cm height and 11.5 cm diameter (831 cm^3). Temperature was logged hourly and this was used to determine daily maximum and minimum temperature.

In 2012 plants were grown at a central location (Waite Institute) before the pots were transferred to experimental sites. 120 pots (14 litre; height 26 cm, diameter between 22 to 28 cm) were each filled with 9 kg soil (hydrated blend of 1 sand: 0.9 unhydrated coco peat by volume). Pots were placed in a bird proof netted area on 4th June 2012 and watered to field capacity. On the 6th June 2012, eight seeds of either cv. Axe, a very early maturing variety or cv. Gladius, an early-mid maturing variety were sown into each of 60 pots at a depth of 3 cm. Pots were watered to field capacity immediately after sowing. Irrigation to field capacity was also provided 3, 7, 14 and 19 days after sowing. Pots were randomly allocated to each of six groups each containing 10 pots sown with each variety. Between the 25th and 26th June 2012 five randomly selected groups of the 20 pots (10 pots containing each variety) were moved to each of five additional experimental locations (Roseworthy, Port Germein 32.95°S, 138.00°E, 49m ASL, Orroroo 32.73°S, 138.62°E, 430m ASL, Lenswood lower valley 34.95°S, 138.82°E, 399m ASL, and Lenswood upper valley 34.93°S, 138.80°E, 471m ASL where we expect a smaller daily diurnal temperature range). The remaining 10 pots of each variety remained at Waite Institute. These locations were selected as the historic (1957-2011) long term averages cover a range of high and low daily mean temperature and high and low daily diurnal temperature range during the growing season (1 April to 31 October) (Table 1).

Table 1. Historic long term (1957-2011) averages of daily mean temperature (°C) and daily diurnal temperature range (°C) during the growing season (1 April to 31 October) for the experimental locations.

Location	Station	Elevation (m)	Daily mean temperature	Daily diurnal temperature range
Lenswood	23801	480	11.4	8.0
Orroroo	19032	428	11.7	12.3
Port Germein	19037	4	14.9	11.2
Roseworthy	23020	68	13.3	10.8
Waite	23031	115	13.3	8.4

The pots remained at the experimental locations until the experiment ended. During the experimental period the pots received regular irrigation to supplement rainfall. Sampling frequency was increased from every 3 weeks until early August then every 2 weeks up until mid-September and then weekly until flowering was completed. One plant was randomly selected for destructive sampling from 5 of the 10 pots at each location. Selection of pots for sampling was approximately random although some bias was introduced to ensure similar number of plants remained in each pot. The harvested plants were assessed for phenological development using the Zadok scale.

Because phenology could not be measured daily timelapse cameras (Wingscapes TimelapseCam8.0 http://www.wingscapes.com/timelapse-cameras/timelapsecam8) were used. Images were obtained hourly during daylight hours. To obtain images of sufficient resolution for analysis only a limited number of plants were monitored at each location.

Patched Point Data climate files were obtained from SILO (http://www.longpaddock.qld.gov.au/silo/) for locations close to each experimental location. This unadulterated climate file was designated Regional climate. A new climate file, designated Local climate, was generated for each of experimental location by substituting daily maximum and minimum temperatures collected from the dataloggers.

Wheat phenology was simulated using the APSIM V7.4 using the Regional climate and the Local climate as inputs. We used mean bias (MB), the root mean square error of prediction (RMSEP) and the Nash-Sutcliffe coefficient (also referred to as modelling efficiency) to compare the observed with simulated phenology.

Results

Temperature measured by dataloggers positioned at the experimental location differed to that obtained from SILO (Table 2). The RMSEP were about 1°C for mean daily temperature and usually slightly more than this for diurnal range in temperature. Distance and elevation differences between the SILO stations and the experimental locations contributed to the observed differences in temperature. Temperature measurements at Lenswood (upper valley and lower valley) showed the most dramatic effect of meso-site on meso-climate. These sites are 1km apart but with an elevation difference of 72m which resulted in changes to the diurnal range in temperature.

Table 2. Mean daily temperature (°C) and average diurnal range in temperature (°C) of Local climate measured using Tinytag dataloggers and Regional climate (obtained from SILO), and the root mean square error (RMSE) of these differences for period from date of sowing to just after completion of 'flowering' at each location. The 2012 experiments used potted plants while the 2011 experiments used field grown plants.

	Local climate		Regional climate		RMSE	
Location	Mean	Diurnal	Mean	Diurnal	Mean	Diurnal
2011 in field						
Roseworthy	13.1	13.6	12.2	12.9	1.1	1.2
Waite	13.6	9.1	12.8	9.3	1.2	1.3
2012 in pots						
Lenswood Lower valley	10.1	10.3	10.9	8.7	1.1	2.5
Lenswood Upper valley	10.4	8.9	10.9	8.7	0.8	1.3
Orroroo	11.3	13.6	10.4	12.2	1.4	2.2
Port Germein	12.9	11.9	11.8	11.6	1.6	1.7
Roseworthy	12.1	10.7	11.1	11.8	1.3	1.7
Waite	12.3	8.4	11.4	8.2	1.3	1.4

Figure 1 shows two examples of the improved match between observed and simulated phenology when paddock level data was used. There were instances when use of Regional climate more closely matched observed phenology (Table 3). Regional climate had similar RMSEP for both cultivars and when calculated for the period from sowing to flowering or only near flowering. Local climate was a better predictor of phenology than regional climate near flowering than of phenology from sowing to flowering (Table 3). This can be seen by the reduction in RMSEP (average of the eight occasions), the increase in the average difference in prediction, and the number of occasions when Local climate improved the simulation (i.e. RMSEP was reduced).

The mean bias showed similar results for RMSEP. The Nash-Sutcliffe coefficient was typically above 0.9 with increases of less than 0.05 when Local climate was used, suggesting that predictions of phenology were accurate when Regional climate was used with only small improvements when Local climate was used.

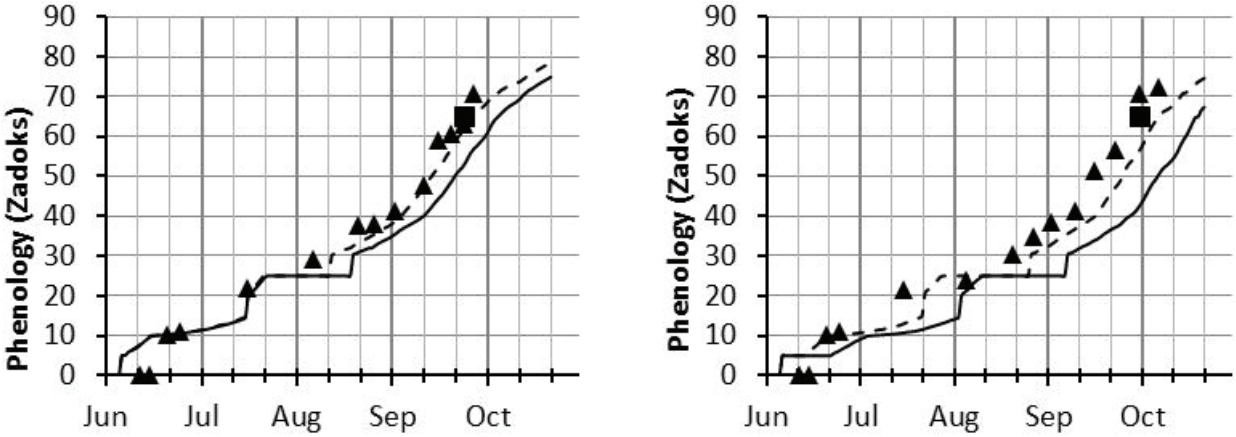

Figure 1. Phenology of wheat cv gladius grown at Waite (left) and Orroroo (right). The observed data from destructive sampling (triangle) and by a timelapse camera (square). Phenology simulated by APSIM using Regional (SILO) climate (solid line) and using Local (Tinytag) climate (dashed line).

Table 3. The average root mean square error of prediction (RMSEP) (in days) of phenology when Regional climate or Local climate were used in APSIM simulations for the eight comparisons (*i.e.* locations and years). The difference in RMSEP between the two climate inputs is shown along with the range in parenthesis and the number of occasions when use of Local climate improved (*i.e.* reduced) RMSEP (maximum of eight occasions).

	Regional climate	Local climate	Difference in RMSEP	Occasions improved
Sowing to Flowering				
Axe	8	7	1 (-2 to 3)	5
Gladius	9	7	2 (-1 to 5)	5
Flowering (Z51 to71)				
Axe	7	4	3 (-5 to 7)	6
Gladius	10	6	4 (-4 to 8)	7

There was no relationship between mean daily temperature and the diurnal range in temperature (r = 0.4), which allows their use as covariates in determining their influence on ability to predict phenology. The predictive accuracy of the APSIM phenology model increased (as measured by a declining RMSEP) with increasing mean daily temperature for phenology from sowing to flowering of cv Axe. Diurnal range in temperature, different measuring periods (i.e. near flowering), or any relationships with cv Gladius were significant. This implies the APSIM phenology model is not biased according to mean temperature or diurnal range in temperature, which in turn implies the phenology model can be used equally well to simulate phenology over a larger or smaller range in mean and diurnal temperatures. As these variables are most likely to change in future warming climates, this suggests spatial analogues which have temperature characteristics of the desired location in a future climate can be used with a high level of certainty to examine projected future climate change.

Conclusions

The simple thermal-photoperiod model of phenology used by APSIM is robust and shows no bias towards mean temperature or diurnal range in temperature making it useful for space-for-time approaches to explore impacts of future warming climates. However, the model generally predicts phenology more accurately when temperature measurements more truly reflect those at the experimental location.

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APSIM Kale appropriately simulates spring and autumn grown forage kale crops in Tasmania

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Abstract
Kale (*Brassica oleracea* var. acephala) is an important winter feed on many dairy farms in the temperate regions of Australia and New Zealand. A key challenge in lifting farm productivity and profitability is understanding the effects of biophysical factors on growth and development of this crop. Biophysical models help in this regard, and can be used to test new production practices, or identify efficiencies that can be gained over current agronomic practices. The objective of this study was to determine if the APSIM kale module appropriately simulated the growth and development of forage kale crops in Tasmania. The results of simulations using site-specific soil and climate data and crop management were compared with data collected from field experiments and commercial kale crops. Comparison of the modelled growth and leaf development to observations in the field showed the model appropriately represented both biomass accumulation and phenological development. Relationship between modelled and observed biomass (n = 35) explained 86% of the variation with a mean bias of -37kg DM/ha over the life of the crop. Relationship between modelled and observed number of leaves (n = 16) explained 93% of the variation with a mean bias of 0.4 leaves over the life of the crop. The APSIM kale module includes predictions of soil water and nitrogen use and once verified will allow more precise management scenarios to be tested and implemented for optimising productivity while minimising the environmental impact of dairy winter forage systems.

Key words
Biophysical modelling, forage crops, dairy systems

Introduction

Pasture growth is low during the winter months on dairy farms in the temperate regions of Australia and New Zealand due to cold temperatures and water logging. This period is also a time when many dairy farmers destock their milking platforms to reduce pugging damage and increase pasture biomass in preparation for calving at the beginning of spring (Nie *et al.* 2001). Consequently during winter dairy cows are often fed sources of forage other than pasture and animals are housed on feedpads or on adjacent blocks to the milking area. Forage kale (*Brassica oleracea* var. acephala) is one such forage source that is grazed during winter on dairy farms. Forage kale produces relatively high yields (between 9 and 12 tDM/ha; Gowers and Armstrong 1994) with a nutritive value that is suitable for feeding to dairy cows (a metabolisable energy content of 11.2 MJ/kgDM and a crude protein content of 9.7%; Westwood and Mulcock 2012). While kale crops are a popular option for dairy farms there are challenges around productivity and quality of feed as well as the fit of kale into forage systems.

Pasture based dairy farms are complex agricultural systems. The interaction between pasture and crop components and the use of supplementary feeds adds complexity in terms of nutrient management and the scheduling of grazing rotations and farm operations (Rawnsley *et al.* 2013). Biophysical and farm system models are used to understand the nature of these interactions. Currently available biophysical modelling tools for investigating dairy farming systems do not include a package for the simulation of winter forage crops. This study aimed to address this gap by evaluating the performance of a recent beta module for forage kale for the Agricultural Production System Simulator (APSIM) biophysical crop model (Holzworth *et al.* 2014) in representing the growth and development of kale crops grown on Tasmanian dairy farms.

Methods

Kale crop growth and phenology

Data was collated for the growth and phenology (number of leaves) of kale crops across five locations in Tasmania, Australia (Table 1). These crops covered a range of soil types, sowing dates and varying levels of input. The details of such are provided in Table 1.

Table 1. Details of Tasmanian grown kale crops used to evaluate the performance of APSIM kale.

Location	Soil type	PA-WC (mm)	Irr/ dry	Cultivar	Sowing date	Plants per m	N Fert (kg/ ha)	End date	No. of biomass obs.	No. of leaf obs.
Mawbanna	Red Ferrosol	171	Irr	Kestrel	2/2/10	11	76	19/6/10	4	5
Redpa	Podsol	178	Dry	Sovereign	7/3/10	28	137	19/7/10	5	5
Cambridge	Brown Sodosol	243	Irr	Sub zero	22/12/09	43	12	12/2/10	1	1
Stonehouse	Brown Sodosol	243	Dry	Sub zero	13/11/09	29	0	13/1/10	1	1
Elliott	Red Ferrosol	143	Irr	Kestrel	13/11/99	45	50	11/2/00	24	4

Evaluation of model performance

Simulations were developed in APSIM (version 7.6) with climate, soil and management parameters that reflected each of the crops. The modelled biomass and leaf number from these simulations were compared to the observed biomass and leaf number from the crops. Comparisons were made by plotting the modelled and observed values as scatter plots and tests for variance reported as the mean bias (as an indication of a bias in under or over predicting modeled values), R^2 and Pearson correlation coefficient (as an indication of the variance between modeled and observed values), model efficiency and mean prediction error (as an indication of how much of the variance in the observed data is explained by the model) and variance ratio and concordance correlation coefficient (as an indication of the deviation between the fitted line between the modeled and observed data and a 1:1 fit). Further details of these statistics are provided in Tedeschi (2006).

Long term simulation of kale crops across Tasmanian dairy regions

Long term (1974 to 2014 inclusive) simulations of kale crop growth were run for four locations that represent the major Tasmanian dairy regions (Bushy Park, Deloraine, Scottsdale and Edith creek). The locations were Bushy Park (black vertosol soil, 576 mm mean annual rainfall), Deloraine (brown kurosol soil, 951 mm mean annual rainfall), Scottsdale (brown dermosol soil, 1001 mm mean annual rain fall) and Edith creek (red ferrosol soil, 1106 mm mean annual rainfall). The following management was used in these simulations:

- The cultivar Kestrel sown into fully cultivated seedbeds on February 1 every year with 35 plants per m^2 established.
- Irrigated to the soils drained upper limit at sowing and then subsequently grown under rain-fed conditions.
- Fertiliser of 30 kgN/ha applied at sowing and a further 40 kgN/ha applied 45 days after sowing
- Grazed and terminated 140 days after sowing.

Results

A comparison of the model predicted values for biomass and leaf number to the observed values showed the model gave realistic representation of kale crop performance in Tasmania (Figure 2). Evaluation statistics for respective biomass and leaf number variables were: An R^2 of 0.86 and 0.93 and Pearson correlation coefficients of 0.93 and 0.96 indicating little variance between observed and modelled values. A mean bias of -37 kgDM/ha and 0.4 leaves indicating no major bias to under or over predicting yield and leaf number. A mean prediction error of 32% and 13% and a modelling efficiency of 0.85 and 0.91 highlighting a high amount of the variance in the observed data was explained by the model. Variance ratios of 0.97 and 1.02 and concordance correlation coefficients of 0.93 and 0.96 indicating little deviation from a 1:1 line of fit between the observed and modelled values.

The median yield at grazing from the long term simulations of kale crops was 7.4, 8.3, 8.4 and 7.6 tDM/ha for Bushy Park, Deloraine, Scottsdale and Edith Creek, respectively (Figure 3). The distribution in yields was similar at each locations and ranged between 6.5 and 8.9 t DM/ha at Bushy Park, 7.4 and 10.2 t DM/ha at Deloraine, 6.1 and 9.7 t DM/ha at Scottsdale and 5.8 and 9.2 t DM/ha at Edith Creek.

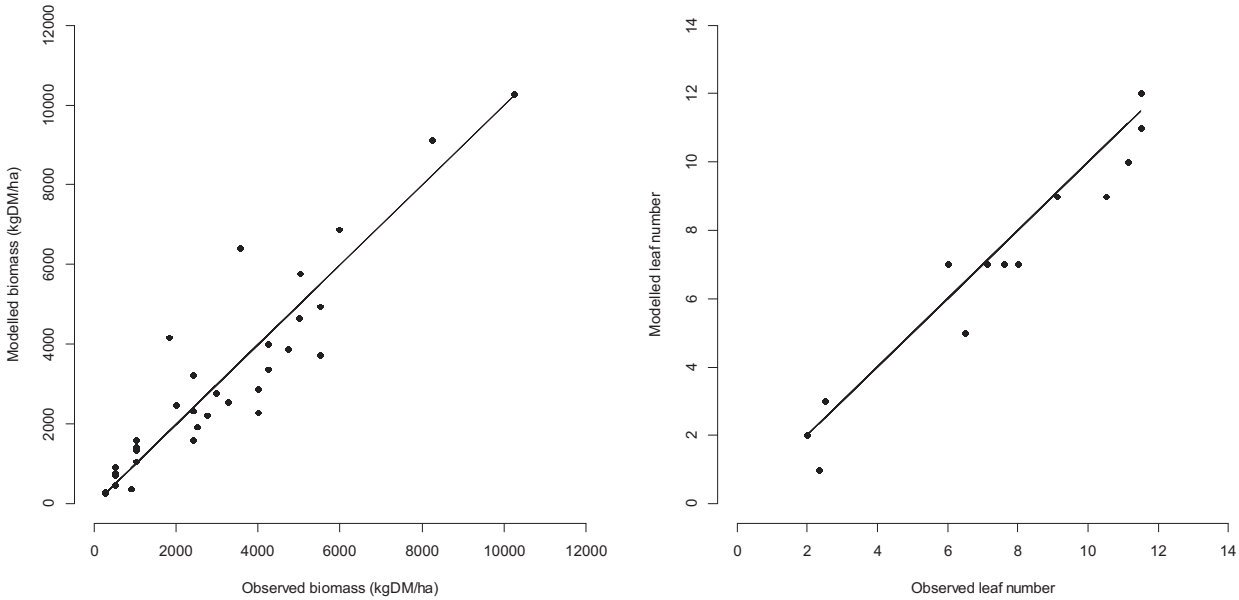

Figure 2. Scatter plots compare the observed and modelled values of biomass and leaf number of forage kale across five locations in Tasmania. The line represents a perfect 1:1 relationship between the observed and modeled values.

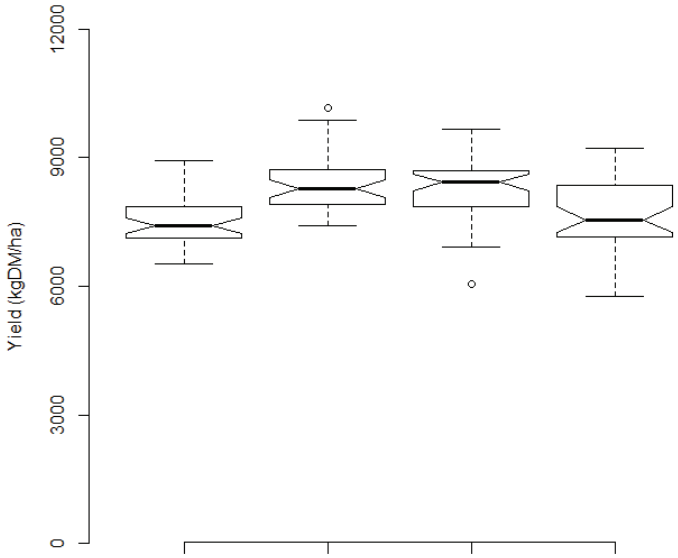

Figure 3. Notched box and whisker plots of simulated kale crop yield over 40 years for four major dairy locations in Tasmania.

Discussion

The summary statistics indicate that the performance of APSIM kale in simulating kale crops grown in Tasmania was similar to or better than the performance of APSIM in simulating the growth of other annual forage crops (e.g. oats, maize, forage rape, forage sorghum; Pembleton *et al.* 2013) and lucerne (Pembleton *et al.* 2011) at similar locations. It was also similar to the performance of DairyMod/SGS (Johnson *et al.* 2008) in simulating pasture growth in Tasmania (Cullen *et al.* 2008; Rawnsley *et al.* 2009). The yield predictions from the long-term simulations of forage kale growth across four major dairy locations were consistent with locally observed yield. The relatively small distributions in forage yields in these simulations reflect the impact that a single irrigation at sowing has on the yield distribution of summer sown, rain fed forage crops in a winter dominant rainfall environments (Harrison *et al.* 2013). This study has shown that the forage kale module in APSIM appropriately represents the growth and development of kale crops

grown in Tasmania. As this module is capable of predicting soil water and nitrogen use it will become an important tool in the simulation of winter forage systems to explore management options that optimises their biophysical, economic and environmental performance in the context of a whole farm system.

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Lamb growth rates on pasture: assessing options for finishing lambs in spring

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Pastures that allow high lamb growth rates in late-spring and early summer are likely to facilitate an increase in production for meat-based livestock systems. This study compared the growth rates and final weights of White Dorper and crossbred lambs grazing six novel pastures over the mid to late-spring period.

Pasture treatments (0.4ha plots) were sown in April 2014 in a replicated complete block design. Pasture treatments included French serradella, bladder clover, forage brassica, lucerne, lucerne + phalaris and arrowleaf clover + chicory with the latter two treatments sown in 1:1 alternate sowing row (tyne) arrangement. Each plot was grazed by 13 lambs (mean starting weight 32.2 kg; five White Dorper (Dorper), five White Suffolk x Merino (WSM) and three White Suffolk x White Dorper (WSD); between 15 October and 2 December. Lambs were weighed weekly after an overnight curfew. Pasture pluck samples were taken weekly and nutritive value tested by NIR. Pastures were managed to ensure the amount of above-ground biomass did not limit intake of lambs.

Lambs grazing the lucerne + phalaris and French serradella pastures reached maximum liveweight on 18 November, lambs grazing bladder clover reached maximum weight on 26 November and lambs grazing forage brassica, chicory + arrowleaf clover and lucerne were still gaining weight at the conclusion of the experiment (2 December). Final liveweights were highest for lambs grazing the arrowleaf clover + chicory pasture (Dorper 43.7 kg, WSD 45.2 kg and WSM 44.0 kg).

Key words
Novel legumes, digestibility, crude protein, lambs

Introduction

Historically pastures containing lucerne (*Medicago sativa*) grazed by crossbred lambs have provided a benchmark for pasture and livestock performance respectively in south-Eastern Australia (Humphries 2012). A range of new pasture species, cultivars and livestock breeds have been introduced into Australian grazing systems (Kilminster and Greeff 2011; Nichols et al. 2012). This study compared growth rates and final weights of weaned White Dorper and crossbred lambs on a range pastures including novel species over the mid to late-spring period.

Methods

Pasture establishment

The experimental site located on Charles Sturt University (CSU) farm at Wagga Wagga, NSW was sown into good moisture on 8-10 April 2014. The experiment included six treatments replicated three times providing 18 plots each 0.4 ha. Treatments were *Ornithopus sativus* cv. Margurita (French serradella), *Trifolium spumosum* cv. Bartolo (bladder clover), *Brassica napus* cv. Stego (forage brassica), *Medicago sativa* cv. SARDI 10 (lucerne), lucerne + *Phalaris aquatica* cv. Advanced AT (phalaris) and *Trifolium vesiculosum* cv. Arrowtas (arrowleaf clover) + *Cichorium intybus* cv. Choice (chicory) with the latter two treatments sown in 1:1 alternate sowing row (tyne) arrangement. All plots were sown at a rate of 35 kg/ha, with the exception of the brassica which was sown at a rate of 9 kg/ha. Phosphorus was applied at sowing to achieve 30 mg/kg Colwell P for all treatments.

Higher than average rainfall was received for autumn 2014 (167 mm cf. 120mm long-term average) and consequently the site (with the exception of the lucerne + phalaris plots) was grazed in early winter with Merino wethers to reduce the pasture biomass. Rainfall July-November totalled 140.4 mm compared to the long term average of 236.8 mm (BOM 2015); consequently all treatments were irrigated between 25 September to 6 October and 29 October to 9 November 2014. During each watering period 50 mm was applied in two irrigation events. This was undertaken to avoid premature pasture senescence in the annual treatments and ensure the experiment could be completed.

Feed on offer was assessed weekly during the grazing period (15 October to 2 December 2014) and remained above 2000 kg DM/ha in all treatments. Pasture pluck samples were collected weekly to simulate the likely diet quality of lambs. Samples were dried at 70 ºC for 48 hours and digestible organic matter in dry matter (DOMD) and crude protein (CP) tested in a commercial laboratory using near infrared spectroscopy with 10% of samples from each treatment tested by wet chemistry.

Sheep management

Weaned lambs were sourced from the CSU flock and local commercial flocks. Lambs were weighed on 7 October 2014 (allocation weight) and drenched (Hatrick, Ancare), vaccinated (5-in-1; Pfizer Animal Health) and treated to prevent fly-strike (Vetrazin spray-on; Novartis Animal Health). Lambs were yarded at 4pm on 14 October 2014, and drafted the following morning into pre-allocated groups, weighed and transported to plots. Allocation to plots within each replicate was based on genotype, source of lambs, sex and weight. Five Dorper, five WSM and three WSD were allocated to each plot, giving a stocking rate of 32.5 lambs/ha. Lambs were subsequently weighed each week after an overnight fast (curfew weight) throughout the experimental period. Lamb weights from 11 November were discarded due to errors experienced with the scales at that time. Of the annual pastures French serradella commenced senescence earlier than other treatments and consequently the lambs grazing this treatment lost a significant amount of weight in the weekly measurement period ending 26 November and were subsequently removed from the experiment. Final weighing date for all other treatments was 2 December 2014.

Statistical analysis

Forage quality and lamb weights were analysed using linear mixed models in Genstat16th edition (VSNi). The random model for lamb weight was replicate/plot/lamb/date. Sex, genotype, treatment, date and their interactions were tested as terms in the fixed model, and start weight was tested as a co-variate and included.

Results

Forage quality: The interaction of treatment and date was significant (P<0.001) for DOMD and CP content of pluck samples (Table 1). At the first measurement (13 Oct) the DOMD of chicory + arrowleaf clover, lucerne and forage brassica treatments were high compared with the other treatments (Table 1). DOMD was lower by the end of the experiment (2 December) in all treatments; however the temporal pattern of DOMD changes differed between treatments (Table 1). CP was highest in the lucerne and chicory + arrowleaf clover treatments at the commencement of the experiment and lucerne had the highest at the conclusion. The CP concentration in forage brassica and serradella was lower than other treatments at the end of the experiment.

Table 1. Mean digestible organic matter digestibility (DOMD) and crude protein content of pluck samples. LSD values allow for both pasture type and time interval comparisons.

date	chicory/ arrowleaf clover	lucerne	bladder clover	French serradella	lucerne/ phalaris	Forage brassica
			Digestible Organic Matter in Dry Matter (DOMD)			
13-Oct	74	74	62	63	63	72
24-Oct	77	76	65	65	62	75
29-Oct	76	73	63	64	61	74
5-Nov	77	73	60	58	56	69
13-Nov	70	67	54	47	55	59
21-Nov	71	63	51	39	52	56
26-Nov	65	72	49	38	54	59
2-Dec	65	64	49	38	53	47
			DOMD average l.s.d. = 4			
			Crude protein (CP)			
13-Oct	29.4	32.3	20.5	23.7	23.2	23.6
24-Oct	30.3	27.9	19.3	20.2	19.0	22.0
29-Oct	28.5	24.9	14.2	19.4	14.7	23.1
5-Nov	24.8	25.8	14.8	15.3	10.4	17.7
13-Nov	17.7	23.3	13.6	10.7	13.0	16.4
21-Nov	19.8	19.5	12.0	7.8	10.0	16.7
26-Nov	13.9	24.4	12.9	8.5	14.1	13.9
2-Dec	15.3	21.9	14.9	9.7	18.1	10.1
			CP average l.s.d. = 4.1			

Lamb weights: The interaction of genotype and sex was significant (P<0.01) for lamb liveweight. The interaction between date, pasture treatment and genotype was also significant (P=0.020; Table 2). Finishing

liveweight of lambs was highest for the chicory + arrowleaf clover and lowest for French serradella and lucerne + phalaris across all lamb genotypes (Table 2).

Table 2. Mean curfew weight of White Suffolk × White Dorper, White Dorper x White Dorper and White Suffolk × Merino lambs grazing pastures from 15 October to 2 December 2014 (l.s.d. = 0.9; l.s.d. values allow for pasture type, lamb genotype and time interval comparisons)

date	chicory/ arrowleaf clover	lucerne	bladder clover	French serradella	lucerne/ phalaris	Forage brassica
	White Suffolk x White Dorper					
15-Oct	32.4	32.4	32.4	32.4	32.4	32.4
21-Oct	33.4	33.1	33.1	33.6	33.9	32.9
28-Oct	35.3	35.1	35.5	35.8	35.6	34.3
4-Nov	37.7	37.1	37.1	37.4	37.4	35.7
18-Nov	41.1	38.8	39.6	38.9	39.0	38.6
26-Nov	43.5	41.2	40.8	37.3	38.1	40.0
2-Dec	45.2	42.6	41.0	*	37.9	41.2
	White Dorper x White Dorper					
15-Oct	32.2	32.2	32.2	32.2	32.2	32.2
21-Oct	32.9	32.6	33.2	33.7	33.6	32.8
28-Oct	35.0	34.9	35.7	35.9	35.5	34.2
4-Nov	37.2	36.5	37.5	37.3	37.3	35.8
18-Nov	40.3	38.5	40.2	39.9	39.0	38.8
26-Nov	42.5	40.6	41.4	38.6	38.7	40.3
2-Dec	43.7	41.7	41.4	*	38.8	41.1
	White Suffolk x Merino					
15-Oct	32.3	32.3	32.3	32.3	32.3	32.3
21-Oct	33.3	32.6	33.4	33.9	33.5	32.9
28-Oct	35.0	34.7	35.2	35.6	35.3	34.2
4-Nov	37.4	36.1	37.3	37.5	37.3	35.7
18-Nov	40.8	38.1	38.7	38.4	37.6	38.5
26-Nov	42.9	40.1	40.0	36.2	37.4	39.8
2-Dec	44.0	41.4	39.6	*	37.6	40.5

Discussion

The results from this research indicate that where pasture availability does not limit livestock intakes, using a high quality late maturing pasture should facilitate high growth rates longer into the growing season and ensure increased lamb slaughter weights. Diet digestibility of lambs grazing chicory + arrowleaf clover or lucerne was high throughout the experiment, and lambs on these treatments continued to gain weight. Lambs grazing bladder clover performed better than expected from DOMD results and lucerne + phalaris worse than expected. Pluck samples from the lucerne + phalaris treatment may have been unintentionally biased by over representation of lucerne and consequently DOMD could have been overestimated, however there is no apparent explanation for lamb growth rates being higher than expected on bladder clover.

The legume and herb mixture of arrowleaf clover + chicory, which was dominated by arrowleaf clover for much of the experiment, produced the highest lamb growth rates and heaviest final weights. Other studies comparing lamb production from arrowleaf clover with subterranean clover or ryegrass have shown that arrowleaf clover can extend the growing season by maintaining higher digestibility later in the season, thus increasing lamb production (Thompson et al. 2010). Lucerne often responds to out of season rainfall and when it does it can provide high quality feed (Humphries 2012) while arrowleaf clover, being an annual, will eventually senesce and decline in quality (Thompson et al. 2010). The advantage of lucerne over arrowleaf clover + chicory therefore is most likely to be expressed later in the summer period than was tested in this study, although interestingly lamb growth rates were lower for lucerne compared to arrowleaf clover + chicory in spring.

Mean liveweights of WSD and WSM lambs grazing French serradella or bladder clover did not differ significantly to lambs grazing arrowleaf clover + chicory after the first 20 days of grazing, thereafter liveweights on bladder clover and French serradella were significantly lower as digestibility reduced and crude protein concentrations declined to a level that could restrict growth rates (Dabiri and Thonney 2004). Liveweights of Dorper lambs did not differ significantly between bladder clover and arrowleaf clover + chicory until much later in the trial (i.e. after 42 days of grazing). It is unclear whether this genotype difference relates to differences in diet selection, metabolism or both. DOMD and CP declined more slowly in bladder clover compared to French serradella allowing lambs to continue to gain weight for longer when grazing bladder clover.

Growth rates on the lucerne + phalaris mixture were initially high, and mean lamb liveweights did not differ significantly from lambs grazing arrowleaf clover + chicory after grazing pasture for 20 days. Growth rates on lucerne + phalaris declined from mid-November with diet quality as the lucerne content of pasture also declined (data not shown) and phalaris was in the stem elongation phase. Although the lucerne in this mixture responded to available moisture late in the trial, growth rates of lambs had not increased by the conclusion of grazing.

Mean liveweight of lambs grazing brassica was significantly lower than other treatments except lucerne after 13 days of grazing (Table 2), despite high digestibility and crude protein content. This, corresponded corresponding to the period when leaf availability was highest. An initial period of slow growth when lambs are introduced to brassica species is was a feature of many other studies (Barry 2013). Despite this initial lag in growth, lambs grazing the brassica gained liveweight throughout the experiment and the diet of lambs grazing brassica transitioned from predominantly leaf to include seed pod and inflorescence.

The experiment highlights the opportunity to exploit hybrid vigour by using a terminal sire in Dorper systems. The WSD lambs had higher finishing weights than other genotypes on the higher value grazing treatments (i.e. arrowleaf clover + chicory and lucerne). The high nutritive values in arrowleaf clover + chicory and lucerne treatments may have allowed this genotype to express the full potential of hybrid vigour and therefore higher growth rates.

Conclusions

Perennial pasture alone does not ensure high late spring and early summer lamb growth rates, vis-a-vis lucerne + phalaris, although early preferential grazing of lucerne and stem elongation in phalaris could have disadvantaged this treatment. The late maturing annual legume Arrowtas (Arrowleaf clover) and Choice (Chicory) performed exceptionally well, outperforming lucerne as measured by final lamb finishing liveweights. Lamb growth rates on forage brassica were disappointing over the 15 Oct to 5 Nov period when compared with French serradella and bladder clover despite higher estimates of dietary DOMD. Reasons for DOMD not always being a reliable predictor of liveweight gain require further investigation.

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Economic value of grazing inter-crops in the high rainfall zone of Southern Australia

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Agronomic management strategies that integrate crop and forage production over summer have the potential to simultaneously increase grain and grazing productivity in the HRZ. Traditionally paddocks are phased from forage to grain production over winter and spring. However, the alternative of inter-cropping forages is expected to reduce 'paddock down time' between crop and pasture, increase stubble feed quality for livestock over summer, and improve soil conditions for grain production. This paper presents a whole-farm biophysical model and farm economic analysis, which were used in combination to determine the productivity and profitability potential of a prime lamb enterprise compared to mixed farming systems that include various forage species grown as an inter-crop with wheat and canola. This analysis showed intercropping was a profitable option for this farm business in south-west Victoria by increasing returns on total capital invested accompanied by a reduction in the variability around such returns. Intercropping with arrowleaf clover or lucerne were the most profitable intercropping options assessed.
Key Words crop modelling, economic risk assessment

Introduction

This paper focusses on arable land in the high rainfall zone (HRZ) of Victoria (annual rainfall > 500mm). This region has experienced significant structural adjustment over the past 25 years, with an increase in cropping and mixed farming systems. Since 1990, the gross value of cropping has increased by 410% in real terms from a low base to $235m, and gross returns from sheep meat has increased by 9% to $502m.

Livestock and cropping enterprises can provide dual income to a farm helping to mitigate against adverse fluctuations in seasonal and market conditions and provide potential benefits to both grazing and cropping enterprises. Agronomic management strategies that integrate crop and forage production over summer have the potential to simultaneously increase grain and grazing productivity in the HRZ. Traditionally paddocks are phased from forage to grain production over winter and spring. However, the alternative of inter-cropping forages, is expected to reduce 'paddock down time' between crop and pasture, increase stubble feed quality for livestock over summer, and improve soil conditions for grain production (less waterlogging, stubble burden, improved nitrogen availability). Furthermore there are also economic benefits from providing high quality feed over summer, potentially enhancing the supply of out of season lamb which could attract premium prices, or conditioning of breeding stock to improve conception rates. Consequently, productivity and profitability are expected to be greater with a well-integrated crop-livestock system at a whole-farm scale. This paper presents the results of a whole-farm biophysical model and farm economic analysis aiming to quantify the productivity and profitability potential of a prime lamb enterprise compared with a mixed farming system, including various forage species which have been grown as an inter-crop with wheat and canola.

Methods

The CAT (Catchment Analysis Tool) model was used to generate the data required to feed into the economic model of this study. CAT simulates biomass accumulation based on extensively used contemporary models (Christy *et al*. 2013) and is readily applicable across all Victorian landscapes (Weeks *et al*. 2008). The biophysical modelling was based on available datasets which encompass the Lamb Directions Case Study 2 farm (Tocker *et al*. 2014), with a total farm area of 950ha, located near Penshurst, in south west Victoria. Local historic climate information, landscape and soil conditions were incorporated, resulting in simulated agricultural productivity relative to that location. The baseline scenario was the Lamb Directions 'Base Farm' where prime lambs were produced from a mix of pasture combinations (740ha of improved pasture, 150ha of lucerne pasture and 60ha of a forage brassica crop). In all scenarios the lucerne and improved pastures were available to stock continuously unless supplementary feeding was required.

A number of whole farm scenarios were run for 50 years (1960-2009), to enable calculation of the economic advantages or disadvantages of incorporating crops into the farm. Crops were incorporated as either monocultures or intercropped with legumes (Table 1) at a range of adoption rates (Table 2).

Crop adoption for each scenario was the total area sown to wheat and canola each year, which were 5%, 10%, 15%, 20% and 25% of the total farm area. However, the area allocated to cropping on the farm is double this, as crop and pasture phases were rotated in each scenario (Table 2) to maintain the legume component in the intercropped scenario (Zhang 2004). This was balanced by reducing each of the 'Base Farm' pasture components proportionally. The area of 'land changed' for each scenario was split into four equal areas to allow a 4 year crop rotation (Table 1). Four different legumes were considered in the intercropping phase of this study, lucerne, strawberry clover, balansa clover and arrowleaf clover. These include prostrate and tall growing varieties, which may affect grain quality at harvest, and differing growth patterns affecting the supply of feed to livestock. Grazing of the crop rotation paddocks (including crop stubbles) was allowed after crop harvest until the sowing of the following crop, based on feed availability.

Table 1. The area of 'land changed' for each scenario was split into four equal areas to allow a 4 year crop rotation with each crop phase proportionally represented in each year (W=wheat, C=canola, P=Clover and Rye grass pasture, Lg=Intercrop legume (either lucerne, strawberry, balansa, or arrowleaf clover depending on scenario), W/Lg= intercropped wheat, C/Lg=Intercropped canola)

Year	Crop monoculture scenario				Crop and legume intercrop scenarios			
	Paddock1	Paddock2	Paddock3	Paddock4	Paddock1	Paddock2	Paddock3	Paddock4
1	W	C	W	P	W/Lg	Lg	C/Lg	Lg
2	P	W	C	W	Lg	C/Lg	Lg	W/Lg
3	W	P	W	C	C/Lg	Lg	W/Lg	Lg
4	C	W	P	W	Lg	W/Lg	Lg	C/Lg

Table 2. Area of farm allocated to each vegetation type for the 50 year modelled scenarios. 'Pasture' component was a mix of perennial ryegrass and clover, 'Brassica' was a forage brassica sown in spring and grazed in December and January to finish lambs, 'Land changed' was a four paddock crop rotation(see Table 2) with each phase represented in every simulation year.

Scenario	Lucerne	Pasture	Brassica	Land changed
Base Farm (ha)	150	740	60	0
5% cropping (ha)	135	666	54	95
10% cropping (ha)	120	592	48	190
15% cropping (ha)	105	518	42	285
20% cropping (ha)	90	444	36	380
25% cropping (ha)	75	370	30	475

Each scenario was run for a 50 year period, 1960-2009, matching the original case study modelled dates. Stocking rates were adjusted from the case study base farm using the criteria that the amount of supplementary feed used by the farm was the same over the 50 year model run. Lambing percentages relative to the stocking rate were set for each year based on that year's seasonal conditions. Average ewe live weights were 65kg. Lambs were sold at 48kg live weight. Ewes were joined on 2 March, to lamb on the 29 July, and weaned on 1 December. Ewes were shorn on 17 January and weaners on 10 December. Wool cut from the ewes was 4.5 kg/head and 0.9 kg/head for lambs (Tocker *et al*. 2014). Data supplied to the economic modelling for each year included total ewe and lamb numbers, numbers of animals sold, wool sold, grain yields (wheat and canola) and supplementary feed purchased.

The whole farm economic analysis model used the biophysical modelled production outputs, combined with price and cost information to generate annual whole farm budgets, using the method described by Tocker *et al* (2013). Key prices and costs for lamb meat, wheat, canola and supplementary feed price, were represented by probability distributions to reflect the variability in costs and prices paid and received by farmers. These different quantities of inputs used and outputs produced, coupled with different prices and costs modelled over many different combinations (10,000 iterations using @Risk, an add-in software

package to Microsoft Excel) enabled a distribution of farm business performance to be calculated. The performance of the base farm system and each alternate farm system scenario was assessed to compare profit and efficiency (economics), debt servicing (finance), additions to wealth (wealth), and business and financial risk (risk analysis).

Results

The results of five development options are presented: a monoculture cropping rotation, and four crop-intercrop rotations incorporating strawberry clover, balansa clover, arrowleaf clover and lucerne with performance of each option being considered relative to the base farm (a grazing enterprise producing prime lambs). Figure 1 shows box and whisker plots for return on total capital (marginal internal rate of return, in real terms) for the base farm (100% pasture), and a 20 % cropped area for each of the five development options. The relative changes resulting from the five development options followed a similar pattern at each level of adoption. The base farm generated an average return on total capital of 5.9%. Planting 20% of the farm into a cereal crop rotation reduced the variability in returns, but also decreased returns slightly, compared to the base farm. All intercropping rotations generated higher returns than the base farm and monoculture cereal crop options. The variability in intercropping returns were also slightly less than for the base farm. Of the intercrop species arrowleaf clover and lucerne gave slightly better returns.

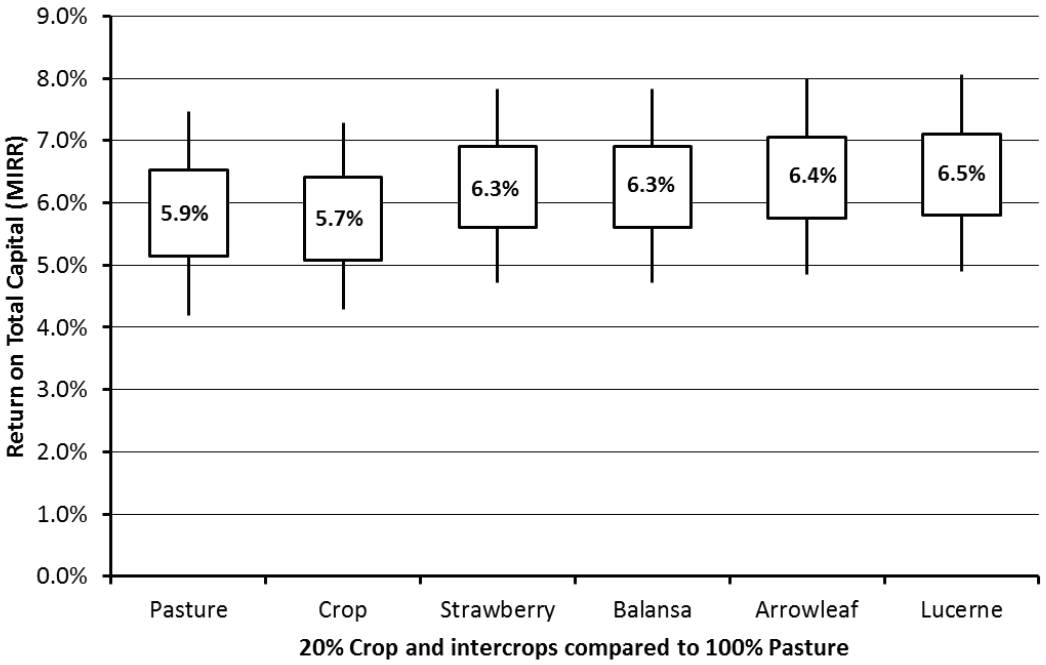

Figure 1. Box and whisker plot (mean, 5,25,75 and 95 percentiles) of return on total capital (marginal internal rate of return, in real terms) for the base farm (100% pasture), 20% of the farm in crop, and 20% intercrop rotations for strawberry clover, balansa clover, arrowleaf clover and lucerne.

A comparison of return relative to risk and planting different proportions of the farm into crop and crop-intercrop rotations for each species is shown in Figure 2. As the area sown in pure crop increased the return on total capital decreased, due to a profitable prime lamb system being substituted for a slightly less profitable cropping system, based on what was considered realistic production for the case study farm. The level of risk, measured as the coefficient of variation in return on total capital also decreased, partly due to the increase in diversification in income streams from crop and sheep, thus reducing the variability around income and costs. For the intercrop options, as the area sown increased, return increased and risk (CV) decreased. Being able to maintain higher sheep numbers than a pure cropping system and also receive cereal crop income enabled for the higher returns, and diversification helped reduce variability. Using the 25% lucerne/cereal intercrop scenario for the farm (for each year this equates to 25% of the area as lucerne and 25 % as lucerne/cereal intercrop in rotation totalling 50% of the farm) gave the highest return on total capital of the options modelled, with approximately 6.8%. Arrowleaf clover and lucerne gave the highest returns relative to level of variability in returns.

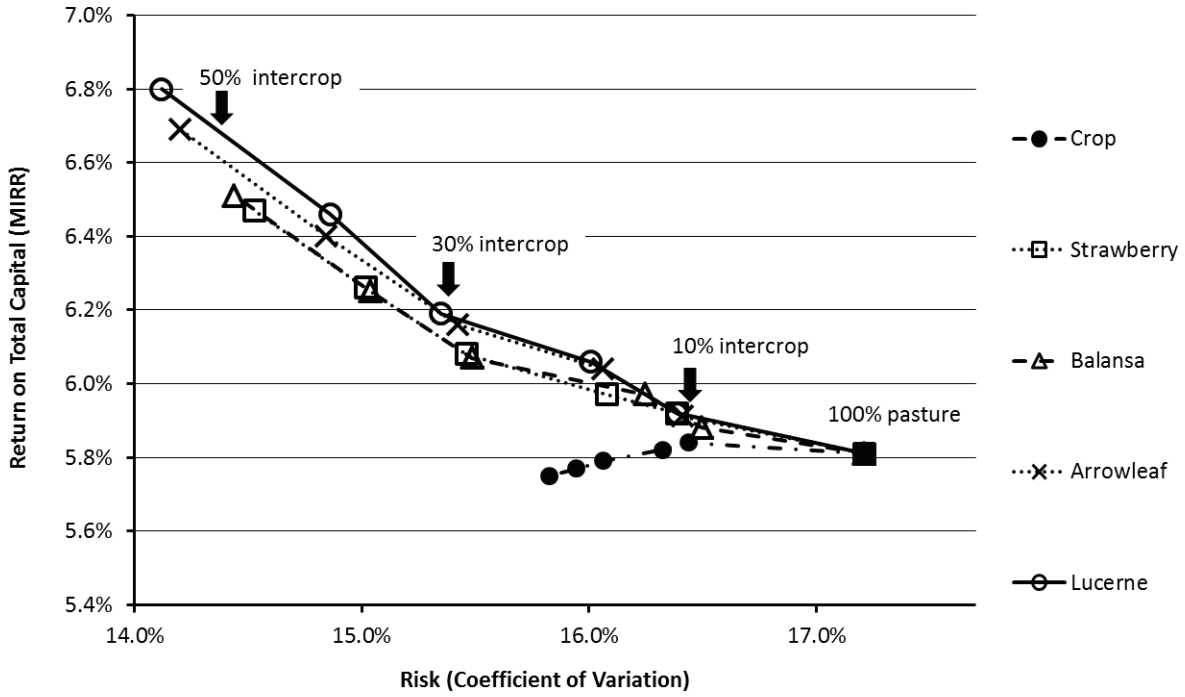

Figure 2. Return on total capital (marginal internal rate of return, in real terms) versus risk (coefficient of variation) for the five development options: cereal crop and each intercrop option at different adoption rates.

Conclusion

This study shows intercropping is a profitable option for the case study farm located in south-west Victoria. The practice increased returns on total capital invested and reduced the variability around such returns. Intercropping with arrowleaf clover or lucerne were the most profitable intercropping options assessed.

In term of risk, measured as the variation in annual economic returns, all intercrop options showed a decrease in risk along with an improved return on capital with increasing adoption. Although this appears to be a 'win-win' solution, these results only represent one location. We expect that the risk and return matrix of results would change in different climates and locations, especially in drier environments.

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Alternate row sowing: a novel approach to maintain sown species in mixed pasture swards

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Abstract
Establishing and maintaining a balanced mixture of perennial and annual pasture species is often difficult, especially in drier environments. One method to reduce the competition between pasture species and to improve the potential productivity and nitrogen fixed by the pasture is to establish pasture species in separate rows (alternate row sowings). An experimental field site was established in the autumn of 2012 near Mirrool in southern NSW. *Medicago sativa* and *Phalaris aquatica* were sown in combination with a range of annual legumes either as a monoculture, mixture, or arranged in alternate rows in 1:1 or 1:2 ratios. Legumes were inoculated with appropriate rhizobia and the sites were fertilised with Starter 15 at 150 kg/ha. Seedling establishment, regeneration and dry matter (DM) were measured each year until 2014. Annual legume seed reserves and nitrogen fixation (N-fix) were measured in 2013. Alternate row sowing improved seedling regeneration and annual legume seed reserves in some situations; however, it did not significantly improve mean DM, mean legume DM or N-fix. In contrast the choice of species combinations impacted on these responses. For example, the inclusion of P. aquatica in the pasture mix tended to increase mean DM, although if N-fix and mean legume DM were to be maintained at acceptable levels, *M. sativa* and *Trifolium subterraneum* were important inclusions in combination with P. aquatica.

Key words
Pasture legumes, alternate row sowing, nitrogen fixation

Introduction

Pastures in crop rotations are expected to contribute to both livestock and crop production. However, maintaining a resilient pasture mixture and in particular, an adequate legume component, is a common challenge in pasture management (Davies 2001). There are now a range of relatively new legume species that can be sown in mixtures and their contribution to crop and pasture systems is not well documented (Nichols *et al*. 2012). Previous research has indicated that maintaining the composition of a sown pasture could be better achieved by changing the row arrangement of components of the sward at sowing (Butler *et al*. 2011). The objective of the current study was to examine the performance of a range of pasture species combinations and sowing arrangements to determine if in principle alternate row sowing could a) improve the productivity and nitrogen fixation of the pasture sward compared to traditional mixed sowing methods, b) improve persistence when annual legume species were sown in wider rows with perennial species and c) determine what likely contribution the different pasture types make to crop or livestock production.

Methods

An experiment was established in the autumn of 2012 near Mirrool (470mm) in southern NSW. The pasture species combinations and sowing arrangements are shown in Table 1. Genus, species, cultivar and common name descriptions are: Medicago sativa cvv. Aurora and Genesis (lucerne); *Phalaris aquatica* cv. Sirolan (phalaris); *Biserrula pelecinus* cv. Casbah (biserrula); *Medicago littoralis* cv. Angel (strand medic); and *Trifolium subterraneum* cvv. Dalkeith, Trikkala and Bindoon (sub clover). All cultivars of the same species (e.g. cultivars Aurora and Genesis; Dalkeith, Trikkala and Bindoon) were sown in equal parts by weight.

The experiment was fertilised with Starter 15 (N:P:S 14.7, 13, 12) in autumn 2012, and soil analysed for phosphorus confirmed a Colwell P of 57 mg/kg. Seedling establishment and regeneration of annual legumes were estimated by counting a 1 m × 0.5 m quadrat with 10 cm × 10 cm grids. Dry matter (DM) was measured in the first year by cutting three 1 m long rows of plant material. Plant material was then dried at 70°C for 72 hours and weighed. In the second and third years the pasture DM was estimated by visually

estimating 10 quadrats per plot and calibrating visual assessments against 9 quadrat cuts per treatment. Botanical composition was estimated in 10 random quadrat locations using the botanal method with 9 calibrated cuts taken for each treatment. Seed yield was measured by extracting the soil and seed from two quadrates (0.2505 m^{-2}) and washing, drying, threshing, cleaning and weighing clean dry seed. Plant samples (shoots) from all measurement times were ground using a puck mill prior to analysing the tissue for nitrogen concentration and the percentage of nitrogen fixed from the atmosphere using 15N natural abundance technique (Herridge et al. 2008). Data were analysed using GenStat version 17 by applying Linear Mixed Models (LMM) with Rep+Row.Column as random effect and LSD values are provided at the 5% level.

Table 1. Species, sowing arrangement, sowing rate and inoculum group descriptions for treatments sown at Mirrool in 2012.

Species	Arrangement	Sowing rate	Inoculum group
T. subterraneum	mono	4 kg/ha	C
M. sativa	mono	3 kg/ha	AL
M. sativa + *T. subterraneum*	mix	3 kg/ha + 4 kg/ha	AL + C
M. sativa + *T. subterraneum*	1:1	3 kg/ha + 4 kg/ha	AL + C
M. sativa + *B. pelecinus*	1:1	3 kg/ha + 1kg/ha	AL + WSM1497
M. sativa + *M. littoralis*	1:1	3 kg/ha + 3 kg/ha	AL + AM
M. sativa + *T. subterraneum*	1:2	3 kg/ha + 4 kg/ha	AL + C
P. aquatica + *M. sativa* + *T. subterraneum*	mix	1.5 kg/ha + 1.5 kg/ha + 4 kg/ha	AL + C
P. aquatica + *M. sativa* + *T. subterraneum*	1:1	1.5 kg/ha + 1.5 kg/ha + 4 kg/ha	AL + C
P. aquatica + *M. sativa* + *T. subterraneum*	1:2	1.5 kg/ha + 1.5 kg/ha +4 kg/ha	AL + C
P. aquatica + *T. subterraneum*	1:1	3 kg/ha +4 kg/ha	C
P. aquatica + *T. subterraneum*	mix	3 kg/ha + 4 kg/ha	C

Sown monoculture = mono, sown mixture = mix, sown species in alternate rows = 1:1 and sown in a higher alternate row ratio = 1:2. In the three way species combinations of 1:1 and 1:2 *T.subterraneum* was sown in each row and the perennials (*P. aquatica* and *M. sativa*) were sown in alternate rows.

Results

Alternate row sowing comparisons: *M. sativa* + *T. subterraneum* sowing arrangements included the traditional mixed sowing arrangement where each species is represented in each row, and the 1:1 alternate row sowing and 1:2 row sowings where each species occupies its own sowing row at a 1:1 or 1:2 ratio. In these treatments seedling establishment (year 1) of *T. subterraneum* was not impacted by sowing arrangement, however by year two *T. subterraneum* seedling regeneration was significantly higher in the 1:2 arrangement compared with the mixture. In year three the 1:2 sowing arrangement had significantly higher regeneration of *T. subterraneum* than the 1:1 which in turn had significantly higher regeneration then the mixture (Table 2). These sowing arrangements however had no significant impact on seed reserves of *T. subterraneum* (Table 2), mean DM, mean legume DM, mean annual legume DM or N-fix (Table 3).

Table 2. Annual legume establishment (plants m^{-2}, 2012) (P< 0.001), regeneration (plants m^{-2}, 2013 and 2014) (P< 0.001) and seed reserves (kg/ha, 2013) (P = 0.004) at Mirrool.

	Establishment	Regeneration	Seed	Regeneration
Species x Row Spacing	Year 1	Year 2	reserves	Year 3
T. subterraneum mono	25	128	153	342
M. sativa mono	0	1	0	0
M. sativa + *T. subterraneum* mix	26	68	53	93
M. sativa + *T. subterraneum* 1:1	22	85	72	156
M. sativa + *B. pelecinus* 1:1	11	23	145	251
M. sativa + *M. littoralis* 1:1	55	91	77	165
M. sativa + *T. subterraneum* 1:2	30	118	87	211
P. aquatica + *M. sativa* + *T. subterraneum* mix	20	66	36	70
P. aquatica + *M. sativa* 1:1 + *T. subterraneum*	22	110	40	48
P. aquatica + *M. sativa* 1:2 + *T. subterraneum*	24	52	46	57
P. aquatica + *T. subterraneum* 1:1	28	116	58	79
P. aquatica + *T. subterraneum* mix	25	95	36	82
LSD	14	49	89	47

Table 3. Mean dry matter (DM), (*P* <0.001), mean legume DM (*P*<0.001) , mean annual legume DM (*P*<0.001) for pasture treatments at Mirrool over the 2012 to 2014 period as well as N-fix measure in spring 2013.

Species x Row Spacing	Mean DM (kg/ha)	Mean Legume DM (kg/ha)	Mean Annual legume DM (kg/ha)	N-fix 2013 (kg N/ha)
T. subterraneum mono	3287	2627	2627	95
M. sativa mono	2979	2790	15	78
M. sativa + *T. subterraneum* mix	3019	2836	590	91
M. sativa + *T. subterraneum* 1:1	2813	2640	921	85
M. sativa + *B. pelecinus* 1:1	3295	3056	1145	98
M. sativa + *M. littoralis* 1:1	2744	2527	807	81
M. sativa + *T. subterraneum* 1:2	2781	2637	1055	85
P. aquatica + *M. sativa* + *T. subterraneum* mix	4433	2178	650	70
P. aquatica + *M. sativa* 1:1 + *T. subterraneum*	4153	2173	632	70
P. aquatica + *M. sativa* 1:2 + *T. subterraneum*	4382	2482	675	80
P. aquatica + *T. subterraneum* 1:1	4096	1056	1056	34
P. aquatica + *T. subterraneum* mix	4792	871	871	28
LSD	1436	1212	840	38

Comparisons of *P. aquatica* + *T. subterraneum* sowing arrangements included 1:1 and a mixed sowing. Sowing arrangement for these species had no significant effect on establishment, regeneration or seed reserves of *T. subterraneum* (Table 2). In addition there were no significant differences to measured mean DM, mean legume DM, mean annual legume DM or N-fix (Table 3).

Wherever *T. subterraneum* was sown in the same row as a perennial species (e.g. treatments *M. sativa* + *T. subterraneum* mix, *P. aquatica* + *M. sativa* 1:1 + *T. subterraneum, P. aquatica* + *M. sativa* 1:2 + *T. subterraneum, P. aquatica* + *M. sativa* + *T. subterraneum* mix and *P. aquatica* + *T. subterraneum* mix) it underperformed in either seedling regeneration for year two or three, or both when compared with treatments sown in alternate rows. Seedling regeneration of *T. subterraneum* and *M. littoralis* in year two was a good indicator of seed reserves measured later that same year, however for this test, data for *B. pelecinus* was excluded as its seedling regeneration was substantially higher than either *T. subterraneum* or *M. littoralis* (Figure 1A, Table 2). Seed reserves of all annual species in year two (2013) were a good predictor of seedling regeneration in year three (Figure 1B).

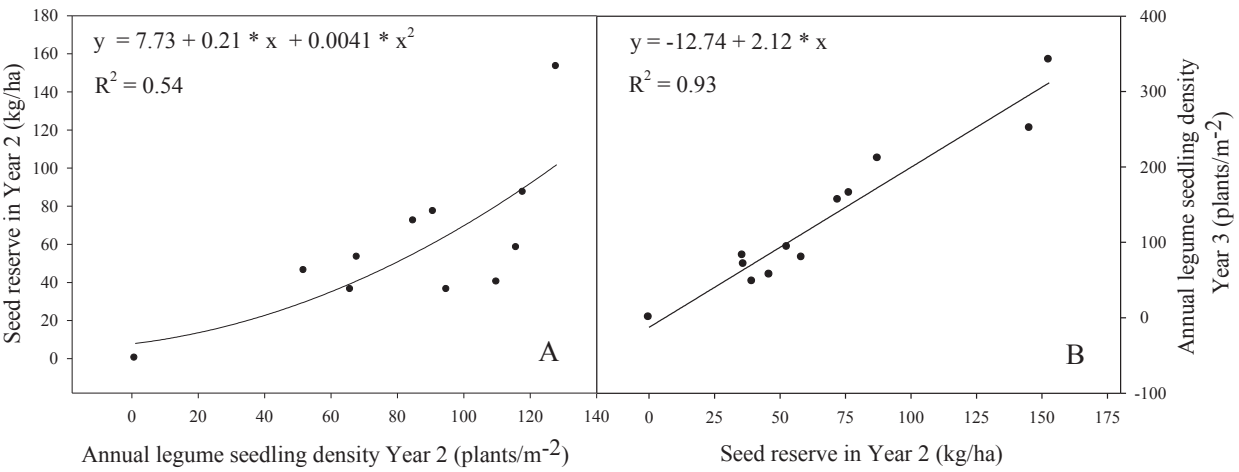

Figure 1. (A) *T. subterraneum* and *M. littoralis* seedling density in year two plotted against seed reserves measured in December 2013 (year 2) (*P*< 0.0001) and (B) seed reserves (kg/ha) of all annual species in year two (2013) plotted against seedling regeneration (plant m^{-2}) in year three (2014) (*P*< 0.0001) at Mirrool.

Species combinations: The highest mean DM was achieved with treatments containing *P. aquatica* and the lowest mean pasture DM was achieved by *M. sativa* + *M. littoralis* 1:1, although this was not significantly lower than a number of other treatments (Table 3). The highest legume DM occurred in treatments *M. sativa* + *B. pelecinus* 1:1, *P. aquatica* + *M. sativa* + *T. subterraneum* mix, *M. sativa* monoculture and *P. aquatica*

+ *M. sativa* + *T. subterraneum* 1:1 and1:2, the lowest mean legume DM was achieved by *P. aquatica* + *T. subterraneum* mix. N-fix was highest in *M. sativa* + *B. pelecinus* 1:1, T. subterraneum mono and lowest in *P. aquatica* + *T. subterraneum* 1:1 and *P. aquatica* + *T. subterraneum* mix (Table 3).

Discussion

Alternate row sowing comparisons: In *M. sativa* + *T. subterraneum*, the 1:1 sowing arrangement had higher year three seedling regeneration compared to the mix, however for *P. aquatica* + *T. subterraneum* the 1:1 sowing arrangement showed no significant difference in seedling regeneration in any year compared to the mix. This may be due to the potentially larger crowning ability of *P. aquatica* relative to *M. sativa*, thus the alternate row sowing of 1:1 may not have been effective at reducing competition from *P. aquatica* against *T. subterraneum*. However the 1:1 arrangement appears effective at reducing competition from *M. sativa* against *T. subterraneum*.

Alternate row sowing did not reduce mean DM, mean legume DM or N-fix, consequently this method of sowing could be used in precision agriculture to target other issues such as, savings in phosphorus application for species with lower critical phosphorus requirements than *T. subterraneum* or perhaps where in the future different pre-emergent herbicide application are directed at different sowing rows.

Species combinations: Species combinations impacted significantly on mean DM, mean legume DM and N-fix. For example treatments containing *P. aquatica* conveyed the highest mean DM yields as all treatment containing this species had mean DM yields > 4000 kg/ha (Table 3). However, where both DM yield and N-fix are important considerations the combinations of *P. aquatic*, *M. sativa* and *T. subterraneum* performed well with N-fix ≥70 kg N/ha which was not significantly different from the highest N-fix value recorded of 98 kg N/ha for M. sativa + B. pelecinus 1:1. These results suggest that maximising pasture production and N-fix can be achieved with a three way mix comprising *P. aquatica* + *M. sativa* and annual legume.

Annual legumes species: Despite having a low initial establishment (Table 2, year 1), B. pelecinus did particularly well in combination with lucerne (1:1) and outperformed its equivalent comparators (*M. sativa* + *M. littoralis* 1:1 and *M. sativa* + *T. subterraneum* 1:1) in seed reserves and year three seedling regeneration (Table 2). It also had a tendency for a higher mean annual legume DM and N-fix, although these differences were not significant at P=0.05.

Acknowledgements

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The effects of deficit irrigation strategies on soil water content under lucerne

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Abstract

A large scale field experiment was conducted at Tatura in northern Victoria, Australia on a red-brown earth, to examine the effects of deficit, or limited, irrigation practices on a range of agronomic and water use characteristics (including soil water) of lucerne. Over four years, eight border-check irrigation treatments (the predominant irrigation methodology of the northern Victorian irrigation region) were imposed that ranged from full irrigation to no irrigation in either single, or over consecutive, irrigation seasons. Soil water contents to a depth of 2.5 m were measured at least six times per year in all irrigation treatments using neutron probes in two access tubes per plot.

Late in the irrigation season, treatment differences in soil water content ranged from 80 mm (0.8 ML/ha) to 190 mm (1.9 ML/ha) over the four years of measurements, and depended on the within-irrigation season rainfall and irrigation strategy. Soil water contents were generally drier under the treatments where irrigation had been restricted and these differences were evident even at depth (>1.5 m). In most years of the experiment, winter rainfall was insufficient to make up the deficit in soil water content by the start of the next irrigation season. These differences in soil water content had some, (up to 0.2 ML/ha), implications for irrigation water intake in the initial Spring irrigation in the following year.

Keywords

Alfalfa, plant water use, restricted irrigation

Introduction

Potential climate change scenarios for the Murray-Dairy region of northern Victoria and southern New South Wales, Australia, indicate an overall decline in rainfall as well as the volume of water available for irrigation of dairy forages. One option for dairy farms to remain viable under these circumstances is to develop forage and management systems that optimise forage production under limiting water supplies. Historically, lucerne has not been a significant component of the feedbase in the Murray-Dairy region (Pembleton *et al*. 2011); however, under future climate regimes it is emerging as a potential forage species in this region because of its adaptability, nutritive characteristics, high productivity and resilience (Bouton 2012).

A large-scale field experiment was conducted at Tatura, Victoria, Australia to investigate the effects of limiting and non-limiting irrigation strategies on the agronomic and water use characteristics of lucerne over four consecutive irrigation seasons (Rogers *et al*. 2015). One of the hypotheses that was tested was whether limited irrigation would create significant differences in soil water content and whether this would have implications on lucerne's irrigation requirement in subsequent years.

Materials and Methods

A field experiment was conducted at the Department of Economic Development, Jobs, Transport and Resources, Tatura Centre in northern Victoria (36°26' S, 145°15' E, elevation 110 m) on a red-brown earth or red sodosol commencing in May 2009. Eight different border-check irrigation treatments (which varied in the timing and application of irrigation water) were applied to lucerne (cv. SARDI 7) over four consecutive irrigation seasons (generally from September to May). The treatments were:

- **T1**. Full irrigation at an interval of 75–90 mm evaporation less rainfall (E–R),
- **T2.** Fully irrigated until a harvest in January in Years 2, 3 and 4 and then no irrigation until the following irrigation season,

- **T3.** Fully irrigated until a harvest in January Years 1, 2, 3 and 4 and then no irrigation until the following irrigation season,
- **T4**. Fully irrigated until a harvest in November in Years 2, 3 and 4, and then no irrigation until the following irrigation season,
- **T5**. Dryland for 1 year, in Year 4,
- **T6**. Dryland for 2 years, in Years 1 and 4,
- **T7**. Dryland for 2 years, Years 2 and 3,
- **T8**. Dryland for 3 years, Years 2, 3 and 4.

In Year 5 all treatments were fully irrigated.

Agronomic measurements that were made on the plots included plant establishment, dry matter production, and plant persistence and are reported in Rogers *et al*. (2015). Soil water content to a depth of 2.5 m, was measured at the end of summer (except in Year 1) and autumn using a neutron probe in two access tubes per plot (calibrated for the site) and expressed in terms of soil water deficit (SWD). Other measurements included climatic data, irrigation and water runoff, and groundwater depth.

Results and Discussion

The soil water profiles at the end of summer (mid-February) and autumn (mid-May) were drier in the restricted irrigation treatments than they were in the fully-watered treatments (Table 1, Figure 1). In autumn of any given year, the difference in SWD between T1 (fully irrigated) and the driest treatments tended to range from 80 to 110 mm. However, in both Year 3 and Year 4, the difference in SWD between treatments was greater at the end of summer than at the end of autumn (viz. 190 and 170 mm respectively) as a result of the amount and timing of rainfall during mid-February to mid-May (Table 1).

Table 1. Soil water deficits (mm to a depth of 2.5 m) for each of the eight irrigation treatments at the end of summer (Years 2 to 4) or autumn (Years 1 to 4).

* Indicates that restricted irrigation was in place at the time of measurement

	Soil water deficit (mm to a depth of 2.5 m)						
Treatment	Year 1	Year 2		Year 3		Year 4	
	2009/10	2010/11		2011/12		2012/13	
	autumn	summer	autumn	summer	autumn	summer	autumn
T1	69	21	41	59	132	97	132
T2	69	25*	108*	178*	166*	205*	223*
T3	122*	20*	110*	160*	146*	177*	192*
T4	61	24*	128*	220*	192*	266*	242*
T5	68	17	33	50	127	229*	211*
T6	154*	15	31	47	120	190*	172*
T7	62	45*	147*	252*	213*	147	193
T8	69	31*	141*	235*	192*	252*	229*
lsd (P=0.05)	19.8	10.9	19.6	25.9	16.1	39.0	36.6

When the winter rainfall was low or average, such as in 2011 (prior to Year 3) or 2013 (prior to Year 5 -viz. 133 mm and 229 mm respectively), the lower soil water contents in autumn tended to carry over to the next irrigation season such that there were differences in irrigation water intakes of up to 0.2 ML/ha at the first spring irrigation between the fully watered and restricted irrigation treatments (Figure 1 and Table 2). In years when the winter rainfall was higher (e.g. in 2010, prior to Year 2, when it was 394 mm from May until the first irrigation in November 2010), there was little difference in the irrigation water intake at the initial spring irrigation between irrigation treatments (Table 2).

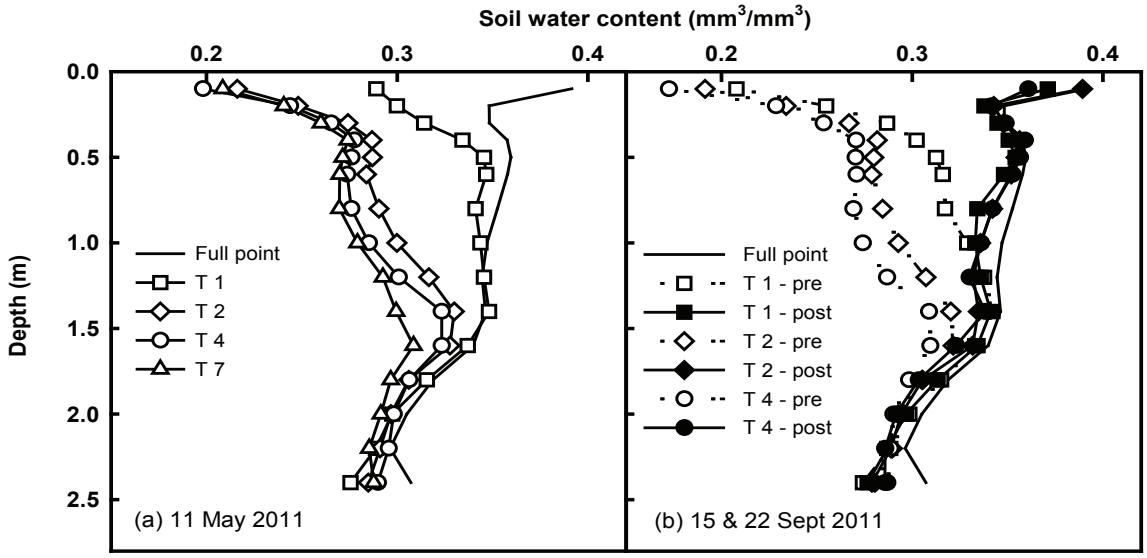

Figure 1. Soil water content profiles of the most extreme treatments late in the irrigation season for Year 2 (2010/11) (a) and pre- and post- the first spring irrigation in Year 3 (2011/12) (b).

Table 2. Irrigation intake (mm) at, and date of, the first Spring irrigation in each of the eight irrigation treatments.

* Indicates that restricted irrigation was used in the previous irrigation season

	Irrigation intake (mm) at the first Spring irrigation			
	Year 2	Year 3	Year 4	Year 5
Treatment	18 Nov 2010	21 Sep 2011	6 Sep 2012	16 Oct 2012
T1	96	96	100	89
T2	99	118*	102*	102*
T3	95*	114*	98*	101*
T4	94	109*	106*	115*
T5	89	91	-	107*
T6	96*	92	-	114*
T7	-	- *	110*	93
T8	-	- *	- *	110*
lsd (*P*=0.05)	4.9	7.8	9.8	9.2

Conclusion

Restricted irrigation of lucerne reduced soil water contents to a depth of 2.5m which, in some years with dry winter / early springs, affected irrigation water intake in the initial Spring irrigation of the following year. Thus, depending on the winter / early spring rainfall, restricted irrigation can have implications on irrigation water-use and irrigation water productivity in subsequent years.

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Optimising Italian ryegrass sowing rates

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Abstract
Research by PGG Wrightson Seeds, Victorian Department of Primary Industries and others at plot and farm scale has demonstrates profits from drilled monocultures of annual ryegrass (*Lolium multiflorum* Westerwold) are maximized with sowing rates of approximately 40 kg Seed/ha, with additional seed generally providing yield benefits for the first two harvests only. Maximum yield occurs at approximately 50 kg/ha and the systems have a diminishing marginal return. In annual ryegrass, the benefits of changing from traditional to demonstrated optimum sowing rates is not trivial, in the order of $100/ha/year (seed and supplement cost dependent).

During 2013 and 2014 PGG Wrightson Seeds undertook sowing rate response experiments on four Italian ryegrass cultivars (*Lolium multiflorum*) with rates between 5 and 80 kg seed/ha. Yield was determined over five and four harvests in 2013 and 2014 respectively. Yield was found to be linearly correlated with sowing rate at the first harvest and the yield of different sowing rates had generally converged by the third harvest. This confirms sowing rate manipulates autumn and/or winter growth rates in Italian ryegrass. Total yield was well modeled by a polynomial (average r^2=0.58) with maximum yield occurring at approximately 60 kg seed/ha.

Assuming seed costs $6/kg, marginal cost analysis indicates profits are maximised at 38 kg seed/ha and 42 kg Seed/ha for a feed value of $200/tonne and $250/tonne respectively. For feed values of $200/tonne and $250/tonne, additional profits of $76/ha and $133/ha respectively can likely be achieved over a 15 kg seed/ha sowing rate.

Key words
Marginal cost analysis, seedling rate, yield response, winter pasture

Introduction
State and private sources generally advise that Italian ryegrass sowing rate should vary with rainfall of the target environment on the premise that low rainfall environments support fewer plant numbers. Recommended sowing rates range from 10 kg Seed/Ha to 30 kg Seed/ha with recommendations usually being environment or ploidy dependent (DPIWE, 2006 and Industry and Investment, 2010).

Research demonstrates that winter yield of both annual (Venuto et al 2004 and DPI, 2007 & 2008) and Italian (Wynn, Hodgson and Andrews, 2011) ryegrass increases with sowing rate, but that this has little effect on spring yield. However, use of ANOVA to compare total yields instead of regression to model observed responses meant defensible sowing rate recommendations were not inferred from these works. Harmer, Sewell and Salmon (2012) presented more data and formalized it into a decision making tool based on marginal cost analysis using fitted response functions. This analysis demonstrates profit increases with sowing rate up to approximately 40 kg seed/ha in annual ryegrass, assuming seed and additional yield is worth $3.6/kg and $150/tonne respectively.

Wynn, Hodgson and Andrews (2011) suggests similar responses to those observed in Annual ryegrass also occur in Italian ryegrass, i.e. yield increases with sowing rate and there is a diminishing marginal return. This study aims to confirm the yield response of Italian ryegrass to sowing rate with a series of trials, and determine optimal sowing rates based on this data.

Method
The trials were drill-sown into prepared seed beds at the PGG Wrightson Seeds Research Farm at Leigh Creek (-37°56'S, 143°95'E), south-western Victoria. The soil is a deep red Krasnozem weathered in-situ

from basalt. The 2013 trials utilised diploid (cv. Knight) and and tetraploid (cv. Feast II and Shogun) Italian ryegrasses and the 2014 trial used a diploid Italian ryegrass (cv. Concord II). Trials were planted in the Autumn (11 April 2013 and 17 April 2014) with a starter fertiliser (44 kg N/ha) applied at the two leaf stage. Trials were fertilised to replace N post-harvest with all other nutrients non-limiting.

The 2013 trial had two replicates of the sowing rates 10, 20, 30, 40, 50 and 60 kg seed/ha and was a randomised complete block design. The 2014 trial was a completely randomised design with a single entry of rates between 5 and 80 kg seed/ha in 5 kg seed/ha increments, i.e. 16 plots. Yield was determined in both trials by full plot harvest of all forage above 50 mm from ground level and the collection of sub samples for dry matter determination. The 2013 trial was harvested five times between 31 July and 11 November 2013 and the 2014 trial was harvested until it could be confidently demonstrated that high sowing rate benefits had disappeared; this required four harvests between 26 August and 4 October 2014.

Results

Figure 1 presents results of the 2013 trial as the mean response of cv. Knight, Feast II and Shogun at each of the five harvests. Figure 2 presents results for the 2014 trial (cv. Concord II only). Results for harvest three of the 2014 trial are unavailable. Based on evidence from the second harvest of this trial (where no response occurred), all previous trials and literature, it is reasonable to assume no response to sowing rate occurred at this third harvest. The absence of this data (given no response was expected) does not affect the recommendations or conclusions of this work. ASReml (VSN International, 2014) was utilised to account for spatial variation in the 2013 data set with treatment fitted as a fixed affect. The 2014 trial layout did not allow spatial analysis, accordingly Figure 2 presents raw data.

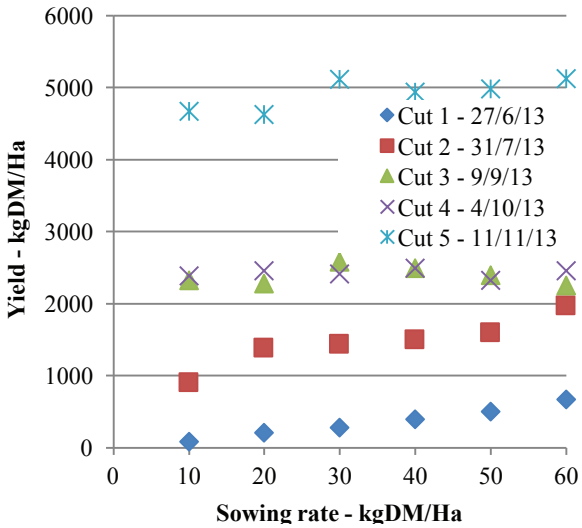

Figure 1. Results from the 2013 sowing rate trial, mean of cv. Knight, Feast II and Shogun at each harvest.

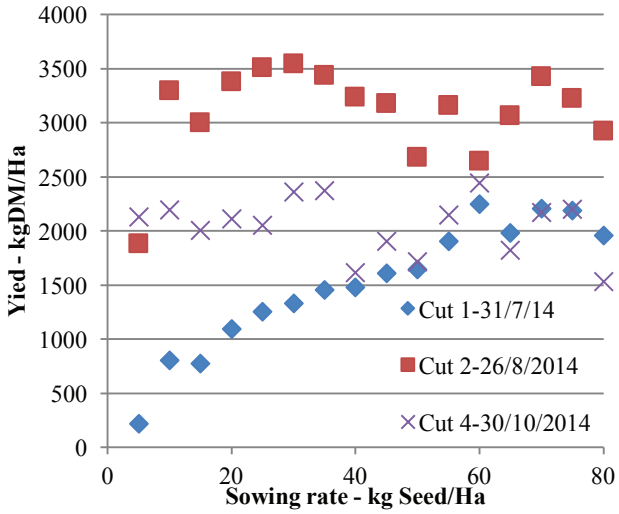

Figure 2. Results of the 2014 sowing rate trial, cv. Concord II only at each harvest.

The affect of sowing rate at each harvest was assessed using linear regression. In 2013, sowing rate of Italian ryegrass significantly effected yield at the first ($p<0.0001$) and second ($p<0.001$) harvests but did not significantly affect yield at later harvests. In 2014, sowing rate affected yield at the first ($p<0.0001$) harvest only.

Previous research has shown that short term ryegrass yield response is well described by a polynomial response function in the sowing range investigated (Harmer, Sewell and Salmon 2012). Table 1 presents polynomial model parameters for total yield (the sum of all harvests) of each individual cultivar and an all cultivar function (see discussion).

Table 1. Summary of model parameters for polynomials fitted to individual cultivars
Significance levels: ***P<0.001; **P<0.05, *P<0.1

Cultivar	Constant	Sowing Rate	Sowing Rate^2	R-Squared
Concord II	8,163***	79.60**	-0.68*	0.52
Knight	9,200***	86.70	-0.67	0.61
Feast II	10,090***	64.45*	-0.52	0.73
Shogun	9,868***	76.65**	-0.46	0.87
All cultivars	-	84.75***	-0.72**	0.58

The constant component of the polynomial response is of no consequence for a marginal cost analysis based sowing rate decision. It is only change in yield (which occurs in winter) from one sowing rate to another (as described by the linear and quadratic coefficients in Table 1) that influence the recommendation.
As such, cultivar curves were standardized by subtraction of a cultivar's respective constant from each cultivar's respective total yield at each sowing rate, allowing data from all cultivars to be combined into a cultivar non-specific response function (Figure 3 whose parameters are in Table 1). This allows us to observe the mean affect of altering sowing rate in isolation from affects such as length of the season etc.

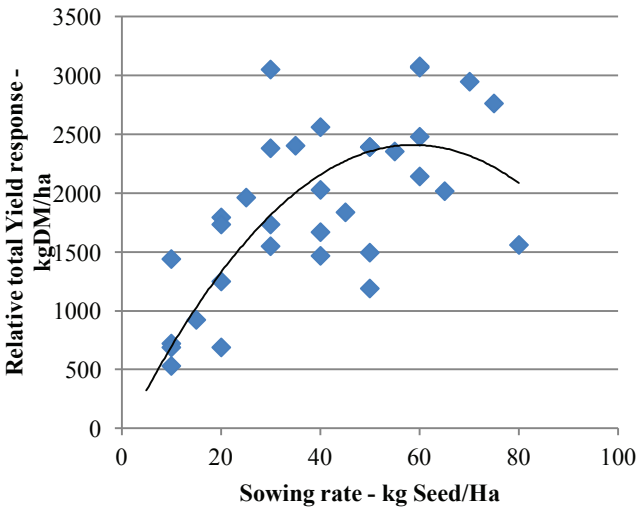

Figure 3. Relative yield response, all cultivars

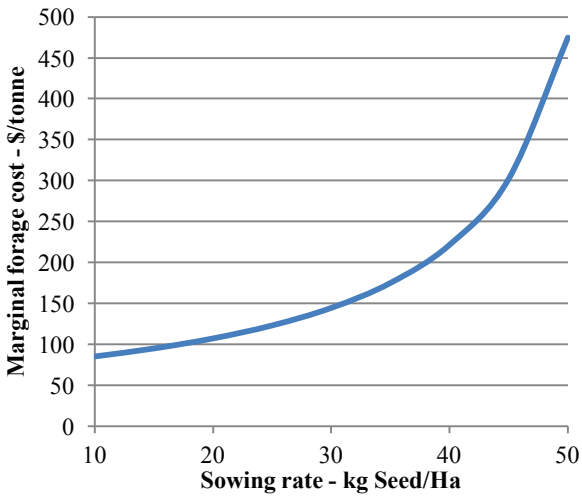

Figure 4. Marginal cost as a function of sowing rate

Discussion and conclusion

Consistent with all previous studies, yield at the first harvest was essentially a linear function of sowing rate and benefits of the higher sowing rate declining or disappearing altogether at later harvests (Figure 1 and 2), presumably due to compensatory tillering at the lower sowing rates. In affect, the higher sowing rate allows maximum production to be brought forward in time. Interestingly, the coefficient for the quadratic component of the cultivar specific function (Table 1) is generally not-significant. Only when they are combined into an "All cultivar" response does the quadratic coefficient become significant.

Figure 3 indicates yield can change by approximately 1,385 kg DM/ha from 15 kg seed/ha to a maximum at approximately 60 kg seed/ha. To make a rational sowing rate decision, the derivative of the "All Cultivar" response equation must to transformed by the inclusion of seed cost (assumed to be $6/kg seed) to a marginal cost curve [$\$/tonne = \left(\frac{1000}{-1.44 \times sowing\ rate + 84.75}\right) \times 6$] see Figure 4.

Whilst all farms will have a different marginal feed cost in mid-winter (Chapman, Kenny and Lane, 2013) when the yield response occurs, if we assume grass grown mid-winter is worth $200/tonne or $250/tonne, it can be seen from Figure 4 that a sowing rate of 38 kg seed/ha or 42 kg seed/ha respectively maximises profits in a monoculture.

Table 2 is provided to highlight the rationale of this recommendation for those unfamiliar with the logic of marginal cost analysis (for an agriculture focused introduction to the concept see Malcolm, Sale and Egan, 1996). Table 2 assumes additional yield is worth $200/tonne and additional seed is costs $6/kg. In the

"Yield" column, the average constant of all cultivars has been added to the "All Cultivars" response function presented in Table 1, thus *Total yield= -0.72×sowing rate^2+84.75×sowing rate+9330*. A diminishing marginal return can be seen in the declining marginal response of yield to subsequent 5 kg seed/ha increases in sowing rate. For sowing rate increases up to approximately 40 kg seed/ha the increase in revenue (due to a reduction in supplementary feed costs) more than offsets the increase in seed cost. As such sowing rate increases up to this point increase profit. Increasing sowing rates beyond this point is not rational as the additional seed cost is more than the value of additional yield grown.

Table 2. Mean effect of change in sowing rate on yield, costs, revenue and profit, assuming seed costs $6/kg and additional yield is worth $200/tonne.

Sowing rate	Yield	Change in yield from lower sowing rate	Change in costs from lower sowing rate	Change in revenue from lower sowing rate	Change in profit from lower sowing rate	Cumulative change in profit from 15 kg seed/ha
kg seed/ha	kg/ha	kg/ha	$/ha	$/ha	$/ha	$/ha
15	10,439	-	-	-	-	-
20	10,737	298	30.0	59.6	29.6	29.6
25	10,999	262	30.0	52.4	22.4	52.0
30	11,225	226	30.0	45.2	15.2	67.2
35	11,414	190	30.0	38.0	8.0	75.2
40	11,568	154	30.0	30.8	0.8	76.0
45	11,686	118	30.0	23.6	-6.4	69.6

Using high seeding rates in mixed swards has not been investigated but would likely result in clover being outcompeted, as such it is unadvisable. However, the responses identified in this research may present an opportunity for producers sowing mono-cultures to increase per hectare profit. These findings suggest research is warranted to determine how far sowing rates can be increased in a mixed sward before clovers are compromised.

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Nitrate and sulphate accumulating shrubs to reduce methane emissions in sheep

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Abstract
Feeding nitrate and sulphate to ruminants is a proven methane abatement strategy. In extensive systems, provision of these compounds as supplements can be problematic due to issues with individual animals selecting an appropriate dose and risk of toxicity. Several Australian native shrub species that are planted by farmers in the low to medium mixed crop/livestock zone accumulate significant concentrations of nitrate and sulphate. The aim of this project was to explore the potential of these shrubs to offer a safe, profitable, environmentally positive and 'natural' means of reducing methane emissions from sheep grazing poor quality stubbles and pasture resides in autumn. This paper describes results from five on-farm benchmarking studies where we investigated use of *Atriplex nummularia, Enchylaena tomentosa and Rhagodia preissii* in grazing systems. Data concerning nutritive profile of the shrubs and variation in dietary intake, liveweight change, wool production and blood plasma indicators of animal health are presented. Sheep tended to maintain or gain weight during the grazing in autumn and we found little evidence of nitrate toxicity as indicated by blood methaemoglobin. The shrubs had high crude protein, low acid detergent fibre, low to moderate organic matter digestibility and variable concentrations of ash, nitrate and sulphate. Voluntary intake by sheep was variable and influenced by the nutritional value of the shrubs and understorey. We concluded that the shrubs offered an opportunity to increase productivity and reduce methane emissions.

Key words
Old man saltbush, greenhouse gas, carbon, salinity, drought

Introduction

Methane represents up to 12% of gross energy that is lost to the ruminant and contributes to greenhouse gas emissions. Diverting metabolic pathways in the rumen away from methane as the major hydrogen sink has been proposed as a practical approach to reduce methane emissions from ruminants (Leng 2008). Nitrate is a promising hydrogen sink and a rough rule of thumb is that for each addition of 1% potassium nitrate to a diet, methane will be reduced by 10% (Leng 2008). Using respiration chambers, van Zijderveld et al (2010) found that lambs fed a basal diet with 2.6% DM nitrate or 2.6% DM sulphate produced 32% or 16% less CH_4 respectively than lambs fed the same basal diet. If fed both, the reduction in methane was 47%. The use of nitrate in combination with sulphate, could therefore offer an avenue for methane mitigation. Sudden introducing of nitrate in the diet may be detrimental to livestock as nitrite can cause oxidation of haemoglobin in the blood (to methaemoglobin) and nitrate can have a caustic effect on gut.

Several Australian native, drought-hardy, shrubs naturally accumulate high concentrations of nitrate and sulphate, including species of *A. nummularia* (old man saltbush), *R. preissii* (Mallee saltbush), and *E. tomentosa* (ruby saltbush) and *Maireana brevifolia* (bluebush). More than 10 years of research demonstrates that these plants are readily eaten by sheep and cattle without reports of toxicity (Ben Salem et al 2010, Revell et al 2013). It is likely that the high salt levels in the plants (up to 25% DM) and/or secondary plant compounds will restrict shrub intake before a toxic dose of nitrate is ingested. There is *in vitro* evidence that fermentation of M. brevifolia in rumen fluid results in less methane per unit of digestible organic matter than many other forage species (Masters et al 2010).

The aim of this benchmarking study was to investigate the utilisation of these shrubs in current grazing systems with a view to generating parameters for future laboratory and respiration chamber experiments. In autumn 2014, we investigated productivity and health of 5 flocks of sheep grazing these shrubs according to the host farmer's typical practice. The information gathered provides parameters for the design of future laboratory and animal house experiments. We hypothesised that the sheep will voluntarily ingest the shrubs and maintain liveweight, condition during grazing and show no evidence of nitrate toxicity (as evidenced by blood methaemoglobin).

Materials and methods

Table 1 lists the sites and grazing dates. At Tammin, we benchmarked sheep in two adjoining wheat stubbles, where animals in one paddock had access to an adjoining 5.3 ha plot of saltbush. Where the understorey was lacking in quantity or quality, cereal hay was provided to animals *ad lib*.

Table 1 Location of plots, description of feed, stocking rates and animals grazing the benchmarking sites

Location	Feed on offer	Area (ha)	Sheep/ha	Days	Animals
Tammin (WA)	Wheat stubble + saltbush	71	2.4	44	Ewes, early pregnancy
Tammin (WA)	Wheat stubble only	81	2.4	44	Ewes, early pregnancy
Quairading (WA)	4 shrub species + hay	15	3.3	34	Ewes, early pregnancy
Cranbrook (WA)	Saltbush + understorey	1.5	27	44	Weaner wethers
Moulamein (NSW)	Saltbush + hay	2	10	36	Weaner wethers
Barham (NSW)	Saltbush + understorey	50	1	36	Ewes, early pregnancy

Animal management and sampling

Paddocks were stocked with Merino sheep a rate of 1 to 27 sheep/ha, rates were representative of farm practice (with the exception of Barham where the stocking rate was lower). Sheep were removed from the plot after the majority of biomass had been utilised or a maximum of 44 days. For each flock, 20 individuals were randomly selected as 'core' animals and used for monitoring of liveweight, condition score change (Suiter 1994), health and wool growth. Wool samples were collected from 10 cm^2 midside patches at the start and end of grazing. The wool was weighed, scoured, reweighed and clean growth was estimated (Langlands and Wheeler 1968). Dietary selection (C_4 shrub vs C_3 stubble, hay or understorey) was estimated using carbon isotopes within a sample of faeces (Norman et al 2009). Blood samples (10ml) were collected from the jugular of core animals for analysis of blood methaemoglobin and biochemical indicators of animal health. Immediately after collection of blood, 2 ml was poured into a small tube and placed on ice and methaemoglobin was determined using the method of Lacey and Rodnick (2002).

Plant measurement and chemical analysis

For the understorey, above ground forage biomass estimates were collected at the start and end of grazing by calibrated quadrate cuts. At Tammin, grain was removed from the quadrates and weighed separately. Shrub biomass was assessed at the start and end of grazing using the 'Adelaide' technique (Andrew et al 1979). Understorey and shrub samples were dried for 48 hours at 60 °C. Samples were ground in a Cyclotech mill (1mm) and used for laboratory assessment of nutritive value. *In vitro* DMD, adjusted to predict *in vivo* DMD, was determined in duplicate using a modified pepsin-cellulase technique (Norman et al 2010). Duplicate samples of 7 AFIA standards (understorey and hay) or 7 shrub standards (for shrubs) with known *in vivo* DMD were included in each batch to allow raw laboratory values to be adjusted to predict *in vivo* DMD using linear regression (AFIA 2007; Norman et al 2010). Concentrations of NDF and ADF of the shrub material were measured sequentially, according to operating instructions, using an Ankom 200/220 Fibre Analyser (Ankom® Tech. Co., Fairport, NY, USA). Total ash was measured according to the methods of Faichney and White (1983). Total N and C were determined by combustion using a Leco CN628 N Analyser. Anions (nitrate, phosphate, oxalate, sulphate and chloride) were extracted with slight modifications of Cataldi et al. (2003) and analysed by HPLC using suppressed conductivity.

Results

The sheep grazed the paddocks from 34 to 44 days, resulting in a range of 36 to 1188 sheep grazing days/ha. Table 2 summarises the animal production benchmarking data collected. Mean liveweight change ranged from a loss of 48g/day to a gain of 130 g/day. The two most heavily stocked sites were where sheep lost weight. Clean wool growth ranged from 44 to 64 g/sheep.day. At Tammin, where we monitored sheep in stubbles with or without access to saltbush, the sheep with access to the shrubs grew faster in the first 3 weeks of grazing (data not presented) but liveweight change was similar after 44 days. Saltbush as a proportion of the total diet during the last week of grazing ranged from 4.5 % (Moulamein) to 27% (Tammin). At each site there was large differences between the 20 individuals monitored, for example one weaner at Cranbrook had 4% saltbush in his diet whereas another ate 42%. Variation was smallest at Tammin where the mature ewes ate 19 to 36% saltbush. There was little evidence of nitrate toxicity as indicated by blood methaemoglobin. One animal at Tammin consistently had levels of 11% but it was in the stubble only 'control group'. The highest blood methaemoglobin level was 15% for a sheep at Moulamein.

Table 2. Sheep liveweight and condition change, wool growth and blood methaemoglobin.

Location	Liveweight change (g/day)		Condition change (units)		C4 in diet* %		Clean wool (g/day)		Clean wool yield (%)		Methaemoglobin (%, final day)		
	Mean	sem	Mean	sem	Mean	range	Mean	sem	Mean	sem	Mean	sem	Range
Tammin (+ SB)	130	14	0.2	0.01	27.0	19-36	4.7	0.13	56	1.8	0.3	0.25	0-4
Tammin (- SB)	136	15	0.0	0.01			4.4	0.13	53	2.1	1.8	0.75	0-12
Cranbrook	-5	11	0.1	0.01	16.0	4-42	4.5	0.11	58	2.9	0.2	0.18	0-4
Quairading	34	4	0.0	0.01	11.1	6-28					1.3	0.39	0-6
Moulamein	-48	11	0.1	0.00	4.5	1-10	5.6	0.21	47	2.5	2.0	0.55	0-15
Barham	107	15	0.2	0.01	5.0	6-12	6.4	0.18	37	2.0	1.1	0.40	0-4

*Estimated C4 shrub component of diet (saltbush) using C isotopes during the final week of grazing. Data at Quairading is only saltbush intake as the other species were C3.

Across sites, the mean edible dry matter (EDM, leaves and stems <3mm diameter) per shrub ranged from 440 to 690 g, equating to a range of 340 – 602 kg EDM/ha. Understorey varied from < 100 kg/ha to about 3t/ha in the stubble plots at Tammin (Table 3).

Table 3. Biomass on offer at the start of grazing at the benchmarking sites.

Site	Shrub EDM (g/shrub)	Shrub EDM (kg/ha)	Understorey (kg/ha)	Grain (kg/ha)	Total (kg/ha)
Tammin (SB+ Stubble)	602	602	2297	161	3662
Tammin (Stubble)	0	0	2959	245	3204
Cranbrook	341	409	1855		2537
Quairading*	384	250	1109		1743
Moulamein*	720	504	100		1324
Barham	690	415	1000		2105

*Sheep were also offered hay of moderate quality (55-58 % OMD) as per usual farm practice

The nutritional traits of the shrubs at the benchmarking sites are presented in Table 4. *Rhagodia preissii* had the highest OMD with 65% and *Enchylaena tomentosa* the lowest at 51%. OMD of *Atriplex nummularia* ranged from 56 to 63%. Fibre levels were generally low, indicating the shrubs would be a good complement to fibrous senesced pastures and crops. Nitrate levels ranged from 0.12 to 0.97% and sulphate ranged from 0.28 to 0.61%.

Table 4. Nutritional profile of the shrub biomass

Site	Sample	OMD %	NDF %DM	ADF %DM	Hemi %DM	OM %	Nitrate %DM	Sulphate %DM
Quairading	*Rhagodia preissii*	65	21	12	9	87	0.21	0.34
	Enchylaena tomentosa	51	32	19	13	78	0.55	0.47
	Atriplex nummularia	57	24	13	10	70	0.23	0.28
Cranbrook	*Atriplex nummularia*	58	25	14	12	77	0.12	0.43
Barham	*Atriplex nummularia*	56	24	14	10	73	0.22	0.43
Moulamein	*Atriplex nummularia*	62	25	13	12	74	0.97	0.61
Tammin	*Atriplex nummularia*	63	23	13	10	75	0.86	0.27

*Stubbles at Tammin: grain OMD of 92%, wheat leaves OMD of 44% and wheat stems OMD 27%.

Discussion

Across sites, sheep generally maintained liveweight during autumn, a time of year when biomass and nutrients are both lacking and producers are generally providing supplements. At Cranbrook, the farmer achieved 1188 sheep grazing days/ha, with minimal liveweight loss (200g/head over 44 days) without provision of supplements. At all sites, the shrubs were planted on soils that were salt-affected so there few other pasture or cropping options. The producers reported that the shrubs were a valued component of their system. Previous work indicates that addition of the shrubs can quadruple the carrying capacity of saline land in autumn (Bennett et al 2012). Other benefits include improved wool growth and quality, reduced vitamin E deficiency and improved meat quality (Ben Salem et al 2010).

The shrubs did provide a source of dietary nitrate and sulphate that was readily eaten by the sheep without any apparent ill-effects. At Tammin in the final week of grazing, the ewes consumed an average of 2 g nitrate and 0.6 g sulphate per day. The maximum level of consumption during the last week was 3.7 g nitrate and 1.2 g sulphate per day. Based on these numbers, toxicity is unlikely and there should be a modest reduction in methane (< 20%). Associated work is examining differences within and between shrub species in nitrate and sulphate accumulation and the impact of soil nutrients. It is clear some shrub species and genotypes within species accumulate more nitrate and sulphate than others and fertiliser can be used to boost nitrate and sulphate concentrations in leaves. The shrubs also contain other plant secondary compounds such as saponins that have been reported to reduce methane. We are now examining fermentability and methane production in an *in vitro* gas production system with rumen fluid, prior to a respiration chamber experiment to quantify *in vivo* productivity and methane emissions in late 2015.

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Evaluation of short-term fodder options between cropping phases in Tasmania

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Abstract

Irrigated forage crops sown in autumn increase land utilisation compared to the common practice in Northern Tasmania of grazing crop stubbles over winter. However, there is little information on which crops best suit this short cropping phase prior to sowing an irrigated winter/spring crop such as poppies or green peas. The aim of this study was to evaluate a diverse range of forage species and varieties that provide the most valuable grazing over autumn and winter. Thirty four varieties of cereals, grasses, legumes and other broadleaf species were selected and dry matter production and nutritive value evaluated.

There was significant variation in DM yields both between and within species. The highest cumulative total DM production for the season (5 - 5.5 t ha^{-1}) was from annual ryegrass and cereals with winter habit. The main production difference between varieties was the timing of maximum growth. Spring varieties of cereals, canola and grain legumes showed rapid early growth but damage to growing points with removal of dry matter reduced subsequent regrowth. In contrast, there was minimal damage to slower growing winter cereals with more prostrate early growth. This work highlights the importance of species and variety selection when determining optimal feed production.

Key words

Forage, intensive grazing, integrated cropping

Introduction

An increase in water availability in Tasmania has stimulated an increase in prime lamb production in mixed grazing/cropping systems. Consequently the popularity of dual-purpose crops has increased. To date cereals and canola have been grown to provide quality winter feed and a harvestable grain crop at maturity. As an extension to this system an increasing number of farmers are seeking other short-term winter feed options to provide quality winter feed. These fodder crops are sown in late summer/autumn, established under irrigation and grazed during winter, before being planted with a spring crop such as poppies or green peas.

Recently, studies have focussed on the impacts of grazing on grain yield of dual purpose crops. For example, Kirkegaard et al. (2012) conducted studies on the management of dual purpose canola, investigating grain yield penalties with time of grazing. However, further work is required on single purpose alternative crop species for grazing. Deciding on the best short-term fodder option is complicated by the range of species and varieties that could fit this role.

This study was a preliminary evaluation of winter dry matter (DM) production and nutritive value (NV) of 34 varieties of cereals, grasses, legumes and other broadleaf species. The specific aims of this study were to (i) determine the species and varieties most suitable for both DM production and NV during the autumn / winter period, (ii) compare multiple forage cuts (simulating grazing) and single forage cut (simulating silage production) in terms of DM production.

Methods

The trial site was located near Bishopsbourne, in northern Tasmania (49°62'S, 146°99'E) in 2010. The soil is a brown dermosol with clay content increasing with depth to a clay subsoil. The previous crop was poppies. The experiment was a randomised complete block design with two replicates with varieties nested within a species block for ease of management. The species and varieties used in the trial are outlined in Table 1. Growing season rainfall (February to August) was 429 mm plus 50 mm of irrigation at establishment.

Management and measurements

The trial was sown on 25th February 2010 with an Ojyard precision drill with 10 rows at 150 mm row spacing. Sowing rates were based on current best practice and final plot size was 8 m x 1.5 m. A basal

fertiliser (9-13-14-4) was applied at 150 kg ha^{-1} and weeds and pests were controlled as required. Half of each plot was cut up to three times (19th April, 10th June and 3rd September), depending on growth stage and maturity of individual varieties. To avoid preferential and overgrazing by livestock, DM cuts were taken with a mower at a height of 50 - 60 mm. These accumulated cuts are herein referred to as '*grazing cuts*' as they simulate grazing events. The other half of the plot was left to grow through the duration of the trial and then harvested, known herein as '*silage cuts*'. This provided an indication of the DM available if the crop was turned into either silage or green manure. Harvest dates were 22ndJuly for early maturing material or 3rd September, prior to the paddock being sown with green peas. Samples were dried at 56°C for 48 hours. For the silage cuts feed value measurements were undertaken. Crude protein (CP), digestibility (DMD) and an estimate of metabolisable energy (ME) were determined by Near Infrared Reflectance at FeedTest Laboratories, Werribee. All data are reported as a percentage of DM.

Table 1. List of the 34 varieties of crop and fodder species evaluated and their growth habit.

Crop/fodder	Species	Variety/cultivar (and growth habit)
Ryegrass	*Lolium multiflorum* Lam	Feast II (Italian), T-Rex (annual)
Oats	*Avena sativa* L.	Graza 50, Quamby, Targa (spring); Bass (winter)
Black oats	*Avena strigosa* L.	Negrita, Saia (spring)
Wheat	*Triticum aestivum* L.	Bolac, Preston, Sentinel (spring); Brennan, Naparoo, Revenue, Tennant (winter)
Triticale	*Triticosecale rimpaui* Wittm	Hawkeye, Tahara (spring); Endeavour (winter)
Cereal rye	*Secale cereal* L.	Oonose (spring)
Barley	*Hordeum vulgare* L.	Dictator, Gairdner, Yerong (spring); Barley E (winter)
Forage rape	*Brassica napus* L. var. *napus*	Ace (mid season); Greenland, Leafmore (long season)
Hybrid rape	*B. campestris* x *B. napus*	Pasja (mid season)
Canola	*Brassica napus* L.	Summit (spring); CBI206 (winter)
Field peas	*Pisum sativum* L.	Morgan, AP2 (spring)
Faba bean	*Vicia faba* L. var. *minor*	Tick bean (spring)
Vetch	*Vicia sativa* L.	Rasina (spring)
Persian clover	*Trifolium resupinatum* L. var. *majus*	Shaftal (annual)
serradella	*Ornithopus sativus* Brot.	Serratas (annual)

Statistical analysis

Separate analyses of variance (ANOVA) were conducted for the silage and grazing yields. Yields of totalled harvests were analysed by ANOVA (Genstat 17, VSN International Ltd). When F tests were significant at $P < 0.05$, the least significant difference (LSD) was calculated at $P = 0.05$ for testing differences between mean DM yields. Forage quality data were not subjected to statistical analysis as samples were pooled over replicates.

Results and Discussion

Accumulated grazing cuts

There were significant differences between the accumulated grazing DM yields of different varieties (Figure 1). In general, there was higher early DM production from barley, triticale, oats and cereal rye varieties compared with the other species, including wheat and ryegrass. Within this grouping the cereals with winter habit i.e. requiring vernalisation (Barley E, Bass oats and Endeavour triticale) tended to be at the lower end of the range of DM yields for each species. However, the subsequent recovery and growth of the more prostrate winter types was superior resulting in higher total DM accumulated across the three cuts. The winter cereals, also including Naparoo, Brennan and Revenue wheat produced over 5 t DM ha^{-1}. In addition, Feast II and T-Rex ryegrass responded well after the first cut and were not significantly different to the winter cereals in accumulated DM yield. Regrowth of the spring types of barley, triticale, oats and rye was generally poor suggesting that the first cut was too severe and damaged the growing points. One exception was the relatively good regrowth of Gairdner barley where many secondary tillers grew after the first cut.

Initial growth of brassica fodder crops was slower than most cereals. Pasja hybrid rape with better regrowth was the best performing brassica in accumulated cuts. Tick beans and field peas grew well initially but percentage DM was low due to high moisture content. The field peas and vetch, with lodging, became difficult to mow and there was no subsequent regrowth in the grain legume species following the first cut. The pasture legume species were slower to establish resulting in increased competition from weeds.

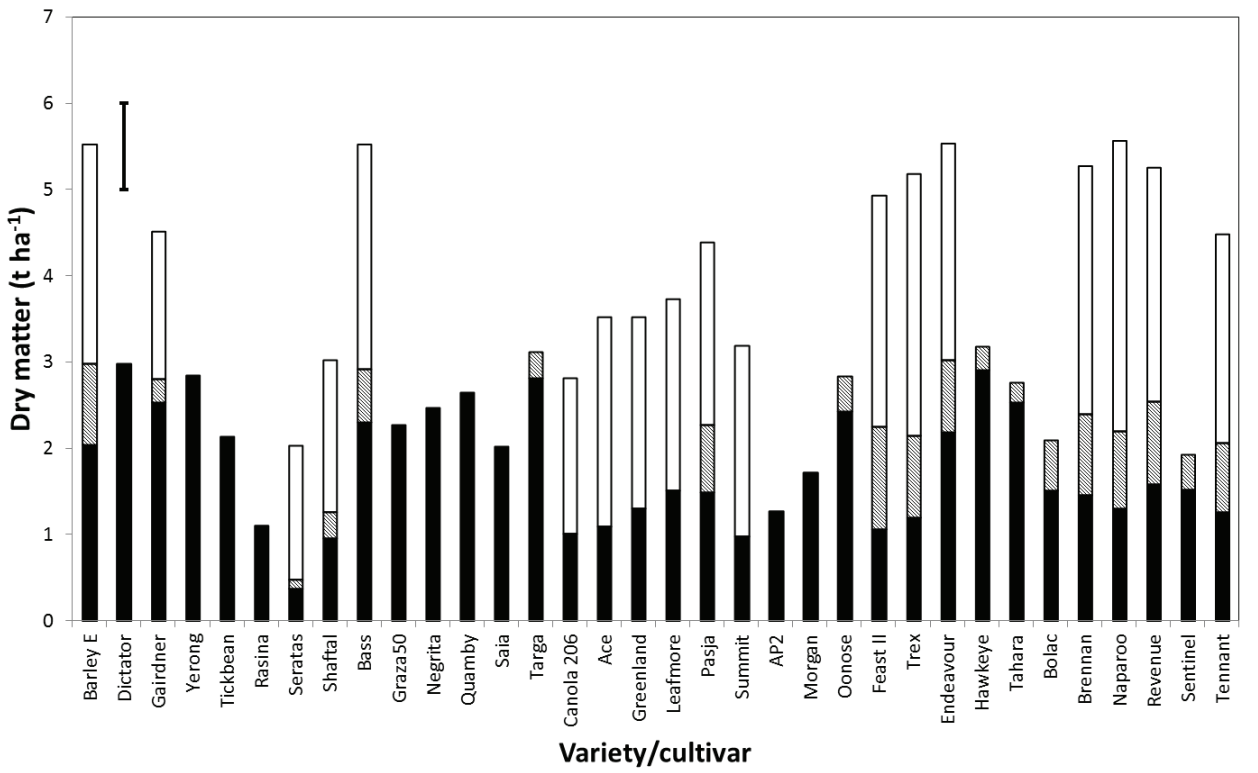

Figure 1. Mean total dry matter yields (t ha^{-1}) of three 'grazing' cuts of 34 forage crops from February to September 2010. The vertical bar indicates $LSD_{0.05}$ of 1.04 t ha^{-1} for comparison of accumulated yields of forages. There were 3 harvests dates but not all forages recovered from early cuts; cut 1 = 53 days after sowing (DAS; solid fill), cut 2 = 105 DAS (diagonal lines), cut 3 = 189 DAS (open fill).

Silage cuts

In general, higher DM was produced in the silage cuts than accumulated in the grazing cuts but the response differed between species and variety growth habit (Figure 2). Spring lines of barley, oats and triticale tended to produce significantly higher DM than winter equivalents, demonstrating the impact of mowing on subsequent regrowth. Regrowth of cereals may be affected by available soil moisture. Kelman and Dove (2009) suggested that regrowth of wheat and oats post grazing was lower than in ungrazed plots in dry springs, but higher in wet springs. However, given the wet conditions during the current study, moisture should not have limited DM production in 'grazing' plots.

The higher yields from grazing cuts compared with silage cuts in Bass oats and barley E is explained by the prostrate growth habit of these two varieties with cuts having less effect on the growing points. Problems with disease were more prevalent in the plots left for silage cuts. In particular field pea and vetch varieties were badly affected by ascochyta and began to rot at the lower stem resulting in low DM yields. Weed competition was also greater in silage cuts of the vetch and pasture legumes, compared with repeated cutting.

The higher DM yields of earlier maturing material are also a function of more advanced growth stage. For example some of the spring cereals were flowering by July. The consequence of this was lower quality NV. For example while the mean CP, DMD and ME values for cereals were 9.7%, 60.4% and 8.8 MJ/kg DM respectively, these values on average were 25 to 30 % higher for winter cereals compared with spring types (data not presented). Neal *et al*. 2010, also reported that repeated cutting or grazing in general results in lower total DM compared with silage cuts due to limiting the time the forage spends in the maximum growth stage. As a consequence the nutritive feed value of repeat cut material is likely to be higher (Neal *et al*. 2010).

The legumes were highest for CP with a mean around 17% (data not presented). While DMD and ME for the pasture legumes were comparable to that for cereals, the grain legumes as a group were much lower due to disease-affected foliage. The brassicas showed considerably higher feed values than the cereals; 14.8%, 78.6% and 11.9 MJ/kg DM for CP, DMD and ME respectively. Overall the fodder brassicas were of higher NV than canola (data not presented).

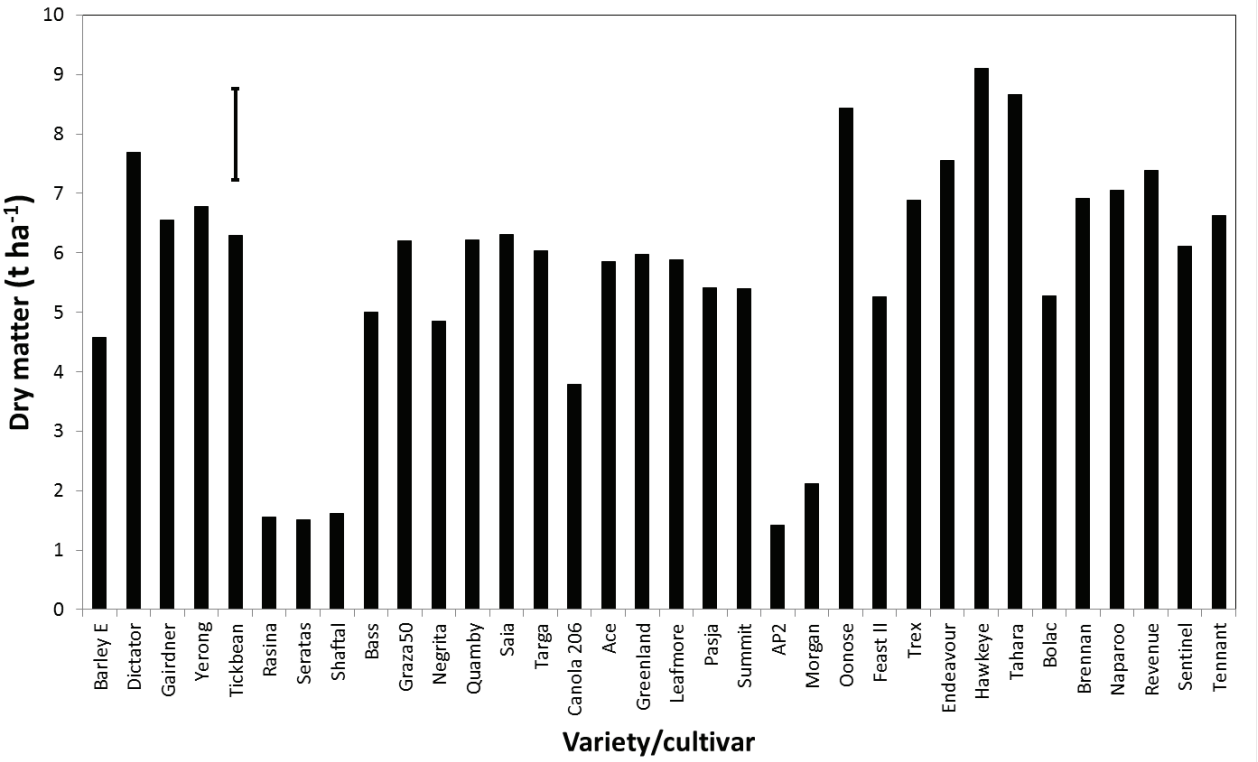

Figure 2. Mean dry matter yields (t ha^{-1}) of the final 'silage' cuts from 34 forage crops. Harvest date depended on crop maturity; early maturing material was cut 22 July and later maturing, 3 Sep 2010.
The vertical bar indicates $LSD_{0.05}$ of 1.55 t ha^{-1} for comparisons between forages.

Conclusions

The work in this study highlights the importance of species and variety selection when filling winter feed gaps. Spring varieties of barley, oats, triticale and rye showed rapid early growth and can be planted for feed supply early in winter. However damage and/or removal of plant growing points reduced subsequent regrowth and therefore caution in grazing these types is required. In contrast, damage to slower growing winter cereals (barley, oats, triticale and wheat) and ryegrass (T Rex and Feast II) with more prostrate early growth habit was minimal and this material can be utilised for extended grazing over winter. With a higher feed value some of the fodder brassicas, in particular Pasja rape, also show potential. From this preliminary screening more detailed evaluation of the varieties with greater potential was conducted.

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100 Years of superphosphate addition to pasture in an acid soil

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Abstract
Pasture-based animal production systems, which occupy a significant proportion of the landscape in Victoria, have historically been nutrient-limited, with phosphorus (P) often the most limiting nutrient. The 'Permanent Top-Dressed' (PTD) pasture experiment was established in 1914 at the Rutherglen Research Station (Victoria, Australia) to investigate the management of this deficiency. The objective of the PTD experiment was to demonstrate the value of adding P fertiliser to increase pasture productivity for lamb and wool production in an era of poor pasture production and limited understanding of the value of nutrient inputs. Of the original treatments which were established, only three have been maintained since 1914; unimproved pasture, as well as improved pasture with 125 or 250 kg single superphosphate/ha applied every second year.

One hundred years of continuous management has allowed us to investigate the long-term effects of applying P to soil, in terms of P, carbon (C), nitrogen (N) and soil acidification. These changes are a response to changes in pasture composition and production over time due to P fertiliser inputs. The analysis of soil samples from 1965 and 2013 have shown the impact of P fertiliser on soil pH, total carbon and nitrogen values, and Olsen P levels. These results show that 100 years of superphosphate has decreased the soil pH while increasing the Olsen P contents of the soil. The very low pH values indicate that future management of the site will require the inclusion of a liming material to counteract the soil acidification, which may also develop new avenues of enquiry focussed on the soil and pasture response to increasing pH.

Key words
Long term trials, phosphorus, nitrogen, carbon, pH

Introduction

Pasture-based animal production systems occupy a significant proportion of the landscape in Victoria, Australia. Productivity in these systems has historically been nutrient-limited, with phosphorus (P) often the most-limiting nutrient affecting pasture growth (White et al., 2000). This P deficiency was identified as early as 1912, leading to the establishment of the 'Permanent Top-Dressed' (PTD) pasture experiment in 1914 at the Rutherglen Research Station (now Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Rutherglen Centre), Victoria. The PTD pasture experiment is the longest running P fertiliser trial under permanent pasture in temperate Australia (Grace, 1993). The objective of the PTD experiment was to demonstrate the value of adding P fertiliser at two rates to increase pasture productivity for lamb and wool production, in an era of poor pasture production and limited understanding of the value of nutrient inputs. The PTD experiment also included a fertiliser plus lime treatment which was terminated in the late 1980s.

Now, 100 years on, it is well recognised that the soils of north-east Victoria still face significant challenges around the availability of P and the influence of low soil pH on P chemistry. One hundred years of continuous management has allowed us to investigate the long-term effects of P fertiliser on the forms and distribution of P and other relevant soil parameters. In 2014, the centenary of the site, extensive soil analysis was conducted to investigate the current status of the PTD soils (Schefe et al., in press). Unfortunately there was limited chemical analysis of the soils over time, with the exception of soil pH which has been recorded in 1948, 1965, 1986 and 2013. A recent search of the soil archives identified samples for the PTD site from 1965. This paper will investigate the changes in soil phosphorus, carbon (C)and nitrogen (N) over the last 50 years, utilising archived soil samples from 1965 and results from 2013 soil sampling.

Methods

The PTD long-term experiment was established in 1914 at the Rutherglen Research Station (36°06'38"S, 146°30'33"E). Of the original treatments which were established, only three have been maintained since 1914. These are: i) unimproved pasture (0kg); ii) 125 kg single superphosphate/ha applied every second year (125kg); and iii) 250 kg single superphosphate/ha applied every second year (250kg). The site consists of three adjacent paddocks of varying sizes: The control is 1.5 ha, the 125kg treatment is 3.1 ha, and the 250kg treatment is 4.6 ha (Figure 1). The average annual rainfall at the site is 590 mm with a winter dominated rainfall pattern. The soil is a bleached eutrophic yellow Dermosol (Isbell, 1996), which is the dominant soil type within the strongly acidic agricultural zone in Victoria (Isbell et al., 1997).

Archived soil samples from 1965 were identified within DEDJTR's soil archives. No details are known regarding the sampling strategy for these samples other than the paddock sampled. They are assumed to be 0-10cm soil depth based on records of sampling in the 1970's. These samples had initially been analysed for reaction(pH), available potassium and organic P (acetic and alkaline) in 1965. For comparison with more recent soil analyses these soils were re-analysed in 2015 using current standard analytical techniques.

The 2013 samples were collected in November with 20 sampling positions per treatment selected to ensure that in field variability would not confound treatment effects. At each soil sampling position, cores were sectioned into depth increments including 0-5, 5-10 and 10-20cm and bulked for each depth. The samples were oven-dried at 40°C for 48 hours were passed through a 2 mm sieve. More details of the sampling strategy and analysis can be found in Schefe et al.(in press).

Soil samples from 1965 and 2013 were analysed for pH (in water and $CaCl^2$), and Olsen P as described in methods 4B4 and 9C2a of Rayment and Lyons (2011). Total C and N were determined using a LECO total C and N analyser (LECO TruMac, LECO Co. St Joseph, USA) after being fine ground in a partially stabilised zirconia (PSZ) ring and puck mill.

Results and Discussion

Soil pH

The PTD experiment is situated within the strongly acidic agricultural zone in Victoria. However, historic pH data from the control and 125kg treatments (Figure 2) has shown that these soils were near neutral in 1948 (pH_{water} of 7.2 for the control treatment).

Figure 1. Aerial photograph of the PTD site showing the 125kg treatment at the top, control in the middle and the 250kg treatment at the bottom (Google™earth, Image © 2014 DigitalGlobe).

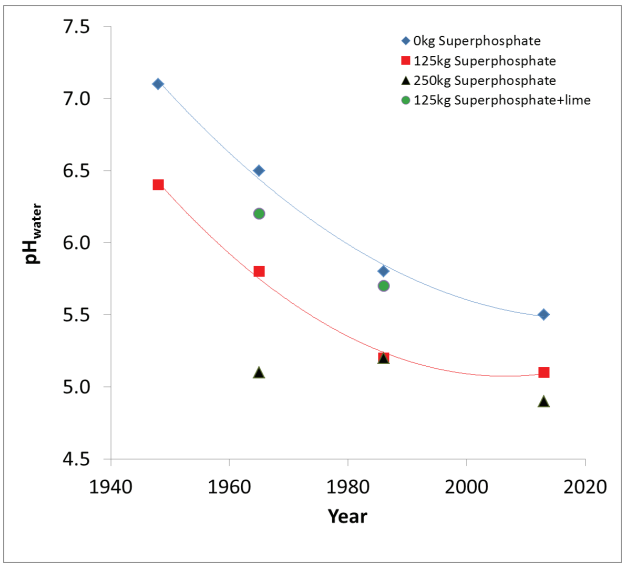

Figure 2. Soil pH_{water} over time showing the 1965, 2013 results and historical data (1948 and 1986) from Ridley et al. (1990).

Prior to finding these archived soil samples from 1965, we were restricted in the investigation of trends over time to data from the control and 125kg treatments. Now with the addition of these samples, the 2013 and archived soils, we can look at the pH of the 250kg treatment and the 125kg treatment (part of which was limed until the late 1980's). Both the control and 125kg treatments have experienced a decline in pHwater of approximately 1.5 units over 65 years (Figure 2). The results from the 125kg-limed treatment appear to track closely with the unfertilised results. In contrast the 250kg treatment was more acidic than the other treatments in 1965, with minimal change over time. By the mid 1980's the 125kg treatment had a similar pH to the 250kg treatment.

Acidification of these soils is believed to be a natural process associated with soil weathering, accelerated acidification in pasture systems through product export (hay, meat and wool), accumulation of organic matter and the leaching of nitrate. By 1939 records show that the fertilised treatments were sub-clover dominated pastures with double the stocking rate of the control, these differences would result in greater rates of product removal and higher nitrogen concentrations and leaching (Figure 3). These processes are distinct from the temporary acidification in the vicinity of superphosphate granules which does not directly contribute to soil acidification (Lindsay, 1979).

From the data presented here and Schefe et al. (in press) , we know that the site has continued to acidify (surface 0-10 cm) over time with soil acidity and associated Aluminum concentrations in the fertilised treatments approaching a level which should impact on production and where broadcasting of lime would be recommended.

Soil Carbon and Nitrogen

Both total C and total N concentrations of the surface (0-10cm) increased in response to fertiliser addition (Figure 3), with both the C and N concentrated in the surface soils (Schefe et al., in press). Interestingly, while there was a difference between the fertilised treatments and the control in terms of total C and N, the difference between the two fertiliser rates is small and this was consistent in both the 1965 and 2013 samples. While Total N has been reasonably consistent over the two sampling times, Total C appears to have increased over time in the fertilised treatments.

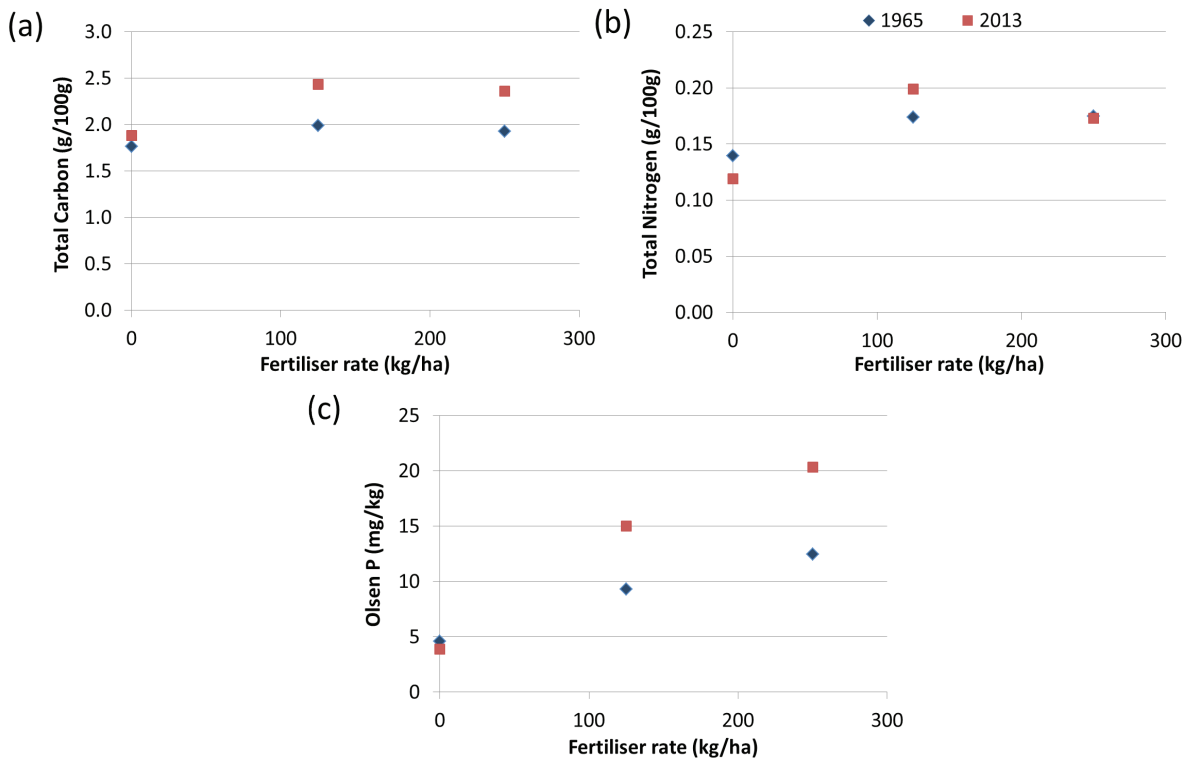

Figure 3. Concentrations of (a) Total C, (b) Total N, and (c) Olsen P measured in surface soils (0-10cm) collected in ♦ 1965 and ■ 2013.

Soil phosphorus

Over the 100 years of the PTD trial there have been 50 fertiliser applications resulting in a total application of 550 kg P/ha and 1100 kg P/ha being applied to the 125kg and 250kg treatments, respectively (assuming a

P content of 8.8% in single superphosphate). This has resulted in an increase in P in the fertilised treatments (Figure 3). Phosphorus fertiliser additions over the 100 years of operation has resulted in a clear distinction in Olsen P concentrations between the control and fertilised treatments.

The critical Olsen P levels for grazed pastures are in the range of 14-15 mg P/kg (Cayley et al., 2002; Gourley et al., 2007). This suggests that the control pasture, in both 1965 and 2013 is likely to be P limited with an Olsen P of 4-5 mg P/kg. In contrast, in the fertilised treatments P would not be limiting production in 2013, with an Olsen P of the surface soil (0-10 cm) of 15 and 20 mg P/kg for the 125kg and 250kg treatments. However, in 1965 the Olsen P would probably still be limiting at 9.3 and 12 mg P/kg for the 125kg and 250kg treatments. In the unfertilised pasture the low constant rate of P suggests an equilibrium between solid and solution P within the soils. Despite the 50 and 100 years of fertiliser application the Olsen P levels are still quite low due to the continual removal of P (hay and sheep) and the high absorption capacity of the soil.

Conclusions

Grazing systems in north-east Victoria have traditionally operated on a rule of thumb rate of application of a bag to the acre of single superphosphate each year, equivalent to 125kg single superphosphate per hectare (Sue Briggs, DEDJTR pers. comm. 2014). The fertiliser rates used on the PTD site over the 100 years are half (125kg) or equivalent (250kg) to this as they were applied every second year.

One hundred years of continuous, non-disturbed pasture has allowed us to investigate the long-term effects of applying P to soil, in terms of P, C, N and soil acidification despite limited soil analysis over time and no replication. After 100 years these rates of fertiliser application have resulted in a notable increase in available P with fertilizer, although we can't determine statistical significance.

For this site to be maintained, and to continue to add value to our understanding of soil processes in acid agricultural soils, future management of this experiment needs to include the application of a liming material to address the declining pH. The future value of this site may lie in the opportunity to better understand how increasing soil pH changes the form and availability of P and N and the ability to maintain soil C.

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Phosphorus-efficient pastures: legume root traits for improved nutrient foraging

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Abstract
The critical soil phosphorus (P) requirement (P supply for 90% maximum yield) of many temperate pastures is determined by the high P requirements of key pasture legumes (commonly Trifolium or Medicago spp.). Legumes that yield well with a lower critical P requirement could reduce the fertiliser requirement of these pastures.

Pot experiments were used to: (i) identify legumes with root traits likely to confer P acquisition efficiency, and (ii) test the impact of these traits on critical P requirement. An initial screen of the root hair length (RHL) and specific root length (SRL) of 13 legumes and two grasses was undertaken. Growth and root morphology of five legumes (*Trifolium subterraneum, T. hirtum, Ornithopus sativus, O. compressus, Biserrula pelecinus*) and one grass (Dactylis glomerata) were subsequently compared in detail using a sandy loam soil (8.3 mg/kg Colwell P) that was amended by applying P to the top 5 cm of the soil profile (0, 15, 30, 70, 135, 250 mg P/kg). Shoot and root growth were assessed after six weeks.

Significant variation in RHL (0.12-0.75 mm) and SRL (98-603 m/g) was found among the legumes, with most being substantially shorter (RHL) or lower (SRL) than the grasses. In the P-response experiment, Ornithopus species (the only legumes with RHL and SRL approaching that of the grasses) had critical P requirements that were less than half that of *T. subterraneum*.

Selecting legumes that maximise root foraging via long, thin roots with long root hairs may reduce the critical P requirement of pastures.

Introduction
The critical external phosphorus (P) requirement (P required for 90% maximum yield) of many temperate pastures is determined by the high P requirements of key pasture legumes (commonly *Trifolium* or *Medicago* spp.; Ozanne et al. 1969). Selecting legumes with lower external requirements for P could reduce the amounts of P fertiliser that need to be applied to pastures because soil managed at lower soil test P concentrations are likely to sorb less P (Simpson et al. 2014). The features of plants that allow them to acquire P more effectively are longer, finer roots with longer root hairs and improved ability to forage for P (Richardson et al. 2011).

This work aimed to: (i) identify potentially useful variation in root morphology associated with nutrient foraging among a range of novel legume species being developed in Australia (Nichols et al. 2007), and (ii) test the impact of these traits on critical external P requirement.

Method
Variation in root hair length and specific root length
The root hair length (RHL) and specific root length (SRL) of 14 legumes and two grasses (Table 1) were assessed in separate experiments. In the first experiment for RHL, a sandy loam soil was steam pasteurised, sieved (<5 mm) and mixed with lime to raise pH ($CaCl_2$) to 5.5. A complete nutrient solution was applied to the soil (extractable P 33 mg/kg; Colwell 1963). Pots (90 mm diam.; 200 mm height) were filled with 1.33 kg of the soil. Two plants were established per pot and inoculated with an appropriate strain of *Rhizobium*. Soil was maintained at approximately 75% field capacity. Plants were grown in a controlled environment cabinet (15-20°C; photon flux density 600 µmol/m^2/s^1; 12 h light/ dark). Four replicates were grown per species. Roots were washed from the soil four weeks after seedling emergence. Root hairs were imaged using a fluorescence microscope fitted with a camera. RHL of ten root hairs was measured on ten images per replicate using Image J (Rasband 1997-2014).

In the second experiment, SRL was assessed on three- and six-week old plants. SRL of the legumes was correlated between harvests (R^2=0.75) and results are only presented for the six-week old plants.

Pots (90 mm diam.; 400 mm height) were filled with 2.746 kg of recycled potting mix containing added superphosphate (extractable P 55 mg/kg; Colwell 1963). One plant was established per pot and inoculated with an appropriate strain of *Rhizobium*. Soil was maintained at approximately 75% field capacity by watering with a P-free nutrient solution. The plants were grown in a glasshouse (15-20°C) under natural lighting in May to July 2013 in Canberra, Australia. Five replicates were grown per species. Plants were harvested six weeks after sowing. Roots were washed from the soil, scanned to determine root length using WinRHIZO (Regent Instruments Inc.) and dry mass determined after drying at 70°C. SRL was calculated as length per unit root mass. Data from both experiments were analysed using ANOVA in R (R Core Team).

Growth in response to phosphorus application

In the third experiment, a subset of the species (Figure 1) was selected to determine growth in response to P application and critical external P requirement. Soil was collected, pasteurised, sieved and limed as per the screen for RHL, and amended with a P-free nutrient solution. Pots (90 mm diam.; 200 mm height) were filled with a bottom layer of 1.0 kg of low P soil followed by a top layer of 0.333 kg of the same soil (11% moisture) that had been amended by mixing with KH2PO4 at rates of 0, 15, 30, 70, 135 and 250 mg P/kg (oven dry soil) to establish six P application treatments (n=5 replicates). This topsoil-subsoil arrangement was used to mimic the stratification of P that occurs in soil under pastures. Plants were grown in a controlled environment cabinet (15-20°C; photon flux density 900 µmol/m2/s1; 12 h light/dark) as microswards with reflective sheets fitted around each pot and raised to equal plant height to reproduce the light conditions in a pasture. Soil was maintained at approximately 75% field capacity. Shoots and roots from the fertilised topsoil and from the subsoil layer were harvested six weeks after sowing. Roots from the topsoil were scanned to determine root length using WinRHIZO (Regent Instruments Inc.). Dry mass of roots and shoots was determined after drying at 70°C. Total P uptake by the plants was determined by ashing root and shoot dry matter at 550°C, dissolving the ash in HCl and determining the P concentration of the solution using malachite green. A Mitscherlich response curve [y = a - b*(e-cx)] was fitted to the shoot dry mass data in R (R Core Team). Critical external P requirement was determined as the P application rate corresponding with 90% of maximum shoot yield. Root mass fraction (root mass in each soil layer as a proportion of total plant mass) was determined. Root mass fraction and total P uptake per unit root length were analysed using ANOVA in GenStat 16th Ed (VSN International).

Results

RHL of the legumes ranged 6-fold from 0.12 to 0.75 mm (Table 1). SRL of the legumes ranged 3-fold from 98 to 320 m/g (Table 1). The key legume species used in temperate pastures in Australia, *T. subterraneum*, had relatively short root hairs and low SRL. The *Ornithopus* spp. and B. *pelecinus* had RHLs and SRLs that approached that of the grasses.

Table 1. Root hair length and specific root length of 12 legume and two grass species.

Scientific name	Common name	Root hair length (mm)	Specific root length (m/g)
Bituminaria bituminosa	tedera	0.12	98
Trifolium tumens	talish clover	0.21	nd
Trifolium incarnatum	crimson clover	0.23	259
Trifolium subterraneum	subterranean clover	0.23	159
Trifolium spumosum	bladder clover	0.25	239
Trifolium ambiguum	Caucasian clover	0.28	187
Trifolium purpureum	purple clover	0.29	177
Trifolium hirtum	rose clover	0.30	290
Medicago sativa	lucerne	0.37	209
Lotus corniculatus	birdsfoot trefoil	0.44	205
Biserrula pelecinus	biserrula	0.56	299
Ornithopus sativus	French serradella	0.73	320
Ornithopus compressus	yellow serradella	0.75	307
Phalaris aquatica	phalaris	0.86	371
Dactylis glomerata	cocksfoot	1.02	603
LSD (*P*=0.05)		0.06	45

Trifolium hirtum was also notable in that it had the longest root hairs and highest SRL amongst the *Trifolium* species. It was surmised that the root traits of these species might confer an advantage for P acquisition efficiency relative to *T. subterraneum*. The growth of these five species in response to P was compared using *D. glomerata* as a benchmark species with a low critical P requirement.

Shoot growth of all species increased in response to addition of *P.* *Dactylis glomerata* had the highest maximum yield and lowest critical external P requirement (Table 2). The *Ornithopus* spp. yielded as well as *T. subterraneum* but achieved this with less than half the amount of applied P (Table 2). *Biserrula pelecinus* and T. hirtum had critical external P requirements that were intermediate to that of *T. subterraneum* but also had significantly lower yields.

Table 2. Critical external P requirement and parameters for a Mitscherlich curve [y = *A* - *B(e^{-Cx})] in response to addition of P for five legumes and one grass species. Different lowercase letters denote significant differences (*P*<0.05; n=5).**

Species	Critical external P (mg P/pot)	*Intercept* Yield at P0 (g/pot)	*A* Max. yield (g/pot)	*B*	*C*
Dactylis glomerata	6.6 ± 0.6a	2.22 ± 0.07a	3.69 ± 0.03a	-1.47 ± 0.06	0.811 ± 0.017
Ornithopus compressus	7.6 ± 0.5a	1.12 ± 0.05b	2.87 ± 0.03b	-1.76 ± 0.06	0.788 ± 0.016
Ornithopus sativus	11.3 ± 0.5b	0.83 ± 0.04c	2.70 ± 0.03c	-1.87 ± 0.06	0.841 ± 0.011
Trifolium subterraneum	26.7 ± 1.3c	0.41 ± 0.05d	2.68 ± 0.05c	-2.27 ± 0.06	0.923 ± 0.005
Biserrula pelecinus	17.3 ± 1.0d	0.36 ± 0.05d	2.04 ± 0.04e	-1.69 ± 0.06	0.885 ± 0.010
Trifolium hirtum	21.1 ± 1.5e	0.36 ± 0.06d	2.03 ± 0.04e	-1.67 ± 0.06	0.905 ± 0.008

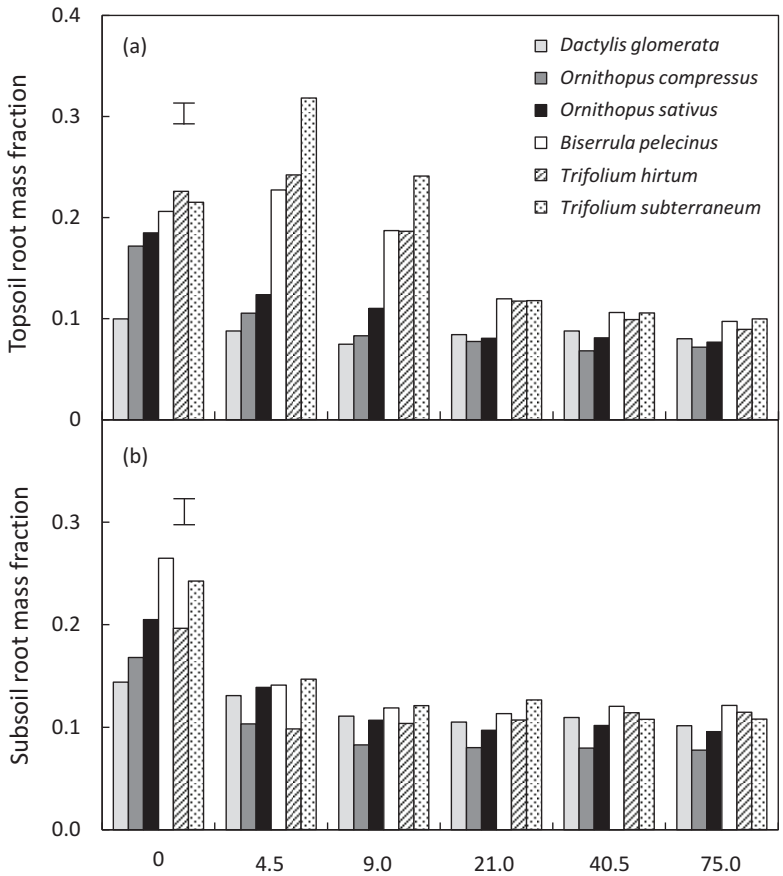
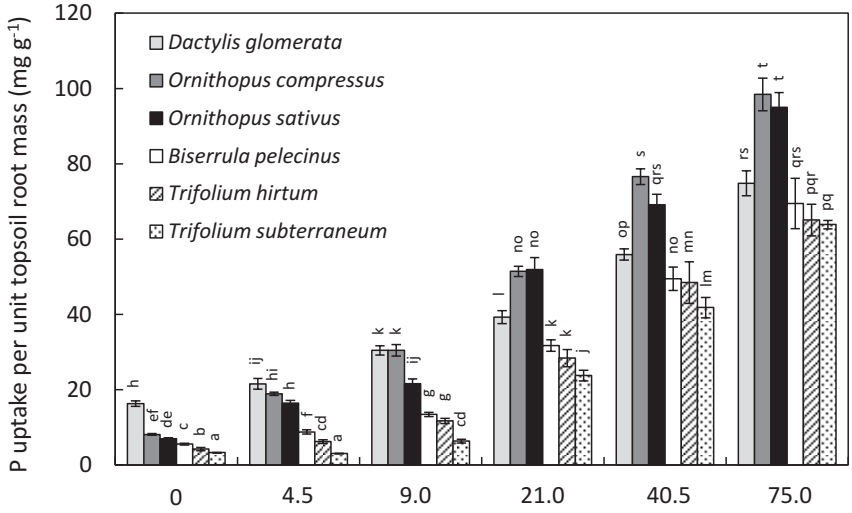


Figure 1. Root mass fraction for (a) topsoil and (b) subsoil roots for five legumes and one grass grown at six rates of P applied to the topsoil. Bar shows LSD for two-way interaction (*P*<0.05; n=5).

All species increased their proportional allocation of dry matter to roots (i.e. root mass fraction [RMF]) in response to decreasing supply of P; the effect was most pronounced in the P-amended topsoil (Figure 1). Species with higher critical external requirements for P tended to allocate proportionately more biomass to roots and demonstrated the largest increases in RMF in response to low P supply. Increases in RMF were most pronounced at levels of P supply at, or just below the critical external P requirement of each species.



P uptake per unit root mass in the fertilised topsoil increased in response to addition of P (Figure 2). The *Ornithopus* spp. generally had higher P uptake per unit root mass than the other legumes.

Figure 2. P uptake per unit mass of roots in the P-fertilised topsoil for five legumes and one grass grown at six rates of P applied to the topsoil. Different letters denote differences for two-way interaction (*P*<0.05; n=5).

Discussion

Trifolium subterraneum and *M. sativa* have short root hairs and low SRL relative to some of the grasses with which they are commonly grown. This limits the ability of these species to forage for P and contributes to their high external P requirement. However, significant variation in root traits associated with nutrient foraging was found among a range of alternative legumes that are being developed for temperate pastures in Australia. Most notably, *O. compressus, O. sativus* and *B. pelecinus* had RHLs and SRLs approaching that of *D. glomerata* and *P. aquatica*.

Ornithopus compressus and *O. sativus* had a critical external requirement more similar to that of *D. glomerata* but yielded as well as *T. subterraneum*. These species achieved this despite allocating proportionately less biomass to roots in response to low P supply. Relatively high rates of P uptake per unit root mass in the *Ornithopus* spp. supported the hypothesis that long root hairs and high SRL allows these species to efficiently explore soil with concomitant advantages for P acquisition that contribute to their low critical external requirement for P.

Conclusion

Selecting legumes that can maximise nutrient foraging via long, thin roots with long root hairs may reduce the critical P requirement of pastures.

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Which fertiliser phosphorus management strategy for maximum clover production and fertiliser phosphorus efficiency?

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Abstract
The application of single superphosphate (SSP) to leguminous pastures is a successful strategy for pasture production in the high rainfall zone of eastern Australia. Typically, the management of fertiliser phosphorus (P) in these grazing systems involves the addition of SSP to the soil surface early in the growing season. However, it is not known whether this is the 'best' strategy for achieving maximum pasture growth with high fertiliser P efficiency. The aim of this study was to ascertain the effect of different fertiliser P management strategies on clover growth and fertiliser P efficiency. This involved using ^{33}P-labelled SSP to measure the direct recovery of fertiliser P in shoots of a subterranean clover pasture at two field sites and under different management conditions (including timing, placement and initial soil P fertility). In general, maximum clover growth and recovery of fertiliser P by clover plants was obtained when fertiliser P was applied to the soil surface early in the growing season. In addition, the recovery of fertiliser P by clover shoots was highest (46% of applied P) in fields that were maintained with soil test P levels near the optimum for pasture growth.

Key words
Agronomic management; Fertiliser fate; Phosphorus cycle; Radiotracer; *Trifolium subterraneum*.

Introduction

The application of single superphosphate (SSP) to leguminous pastures has been a highly successful strategy for improving and maintaining high pasture yields in the high rainfall zone of south-eastern Australia (Cayley *et a*l. 1999). Single superphosphate is often applied to the soil surface very early in the growing season (autumn). Some of the reasons for favouring broadcasting P early in the growing season include: 1) lower fertiliser costs than in later months; 2) financial incentives to invest in farm operations prior to the end of the financial year; 3) drier soils at the start of the year that favour spreading operations compared with winter, and/or; 4) inability to apply nutrient at depth in permanent pastures. However, there are no published studies that have determined the direct recovery of fertiliser P from SSP (here termed 'fertiliser P efficiency') in leguminous pastures during the first growing season after fertiliser application under field conditions. In addition, there is little information about the 'best' strategy for maximizing pasture production with high fertiliser P efficiency. In developing this set of experiments we hypothesised that the recovery of fertiliser P in clover shoots may be higher when it was applied to pastures mid-season compared to early-season application because roots would be well established and better able to intercept fertiliser P, and that fertiliser placed at depth may be better positioned for root uptake compared to that applied to the soil surface. In this study, we use a novel, rapid and cost-effective approach to label SSP with a ^{33}P radiotracer (^{33}P-labelled SSP), and then applied this to clover monocultures under field conditions to measure the direct recovery of the applied fertiliser P.

Materials and Methods

Field experimentation and management

Two field sites under permanent pasture with low soil P fertility were selected in the temperate region of south-eastern Australia. One field site was located on a property near Inman Valley (sand in the 0 – 20 cm layer), South Australia (35°29'39" S, 138°27'21" E), and the other was located at the CSIRO Ginninderra Experiment Station (sandy loam in the 0 – 20 cm layer), near Hall, the Australian Capital Territory (35°11'49" S, 149°05' 19" E). Some chemical properties of the soils collected from both field sites are shown in Table 1.

A clover pasture was established and 'open-ended' PVC cylinders (15 cm (diameter) × 18 (height) cm) were inserted 15 cm into the soil at each site. Basal nutrients (B, Ca, Cu K, Mg, Mo, S and Zn) were applied across both sites. The fertilised treatments involved the addition of ^{33}P-labelled SSP granules to supply ~ 20 kg P ha^{-1} (~ 4 MBq core^{-1}). Treatments included: 1) a control (no added fertiliser P); 2) application of ^{33}P-labelled SSP to clover pastures at early-season on the soil surface (Ginninderra – April and Inman Valley – June); 3) application of ^{33}P-labelled SSP to clover pastures at mid-season on the soil surface (Ginninderra – July and Inman Valley – August), and; 4) application of ^{33}P-labelled SSP to clover pastures at early-season placed 6 cm below the soil surface (deep). Details of the radio-labelling technique is reported in McLaren et al. (2014). All treatments consisted of six replicates arranged in a randomised block design. If needed, sites were irrigated to ensure the cumulative rainfall throughout the growing season was at least decile 5 (average rainfall), which was not required at the Ginninderra field site.

Table 1. Chemical properties of the soils used in this study. Analyses were carried out on soil samples collected prior to fertiliser addition to the subterranean clover pasture.

Location	Depth (cm)	pHw (1:5)	[A]ECw (µS cm^{-1}; 1:5)	[B]TOC (%)	[C]TON (%)	[D]Colwell P (mg kg^{-1})	[E]PBI	[F]Total P (mg kg^{-1})
Ginninderra,	0 – 2.5	5.5	96.5	3.4	0.27	30	36	439
ACT	2.5 – 5	5.1	54.7	1.7	0.15	14	43	381
	5 – 10	5.2	36.0	1.2	0.10	9	44	346
	10 – 20	5.4	26.0	0.6	0.05	6	14	285
Inman Valley,	0 – 2.5	5.8	47.9	2.1	0.18	12	11	216
SA	2.5 – 5	5.8	35.9	1.7	0.15	12	38	185
	5 – 10	5.6	34.2	1.2	0.10	16	13	170
	10 – 20	5.4	20.1	0.6	0.05	12	12	127

[A]EC, electrical conductivity, [B]TOC, total organic carbon, [C]TON, total organic N, [D]Bicarbonate extractable P (1:100 soil:solution), [E]PBI, phosphorus buffering index, [F]Total soil P using XRF

The existence of a long-term P fertiliser experiment at the CSIRO Ginninderra Experiment Station also provided an opportunity to investigate the recovery of fertiliser P in clover shoots under different levels of initial soil P fertility (Simpson *et al*. 2010). This experiment was established in 1994 and included treatments designed to maintain soil P fertility in the topsoil layer (0 – 10 cm): 1) fields receiving no P fertiliser (P0: control – native soil P fertility between 4 – 6 Olsen P kg^{-1}); 2) fields receiving fertiliser P to maintain a soil P fertility between 10 – 15 Olsen P kg^{-1} (P1), which is a near-optimum soil test P concentration for pasture growth at this site, and; 3) plots receiving fertiliser P to maintain a soil P fertility between 20 – 25 Olsen P kg^{-1} (P2). A subterranean clover monoculture was established in fields at each soil P fertility level (n=3) and ^{33}P-labelled SSP was applied to the soil surface at the 'early-season' application time, using the methods described above. Treatments were arranged in a randomised block design. Experiment details of the long-term P fertiliser experiment and background information have been reported by Simpson *et a*l. (2010).

Four harvests were collected at the Inman Valley field site and five harvests collected at the Ginninderra field sites. The final harvest at Ginninderra and Inman Valley field sites were in November and October, respectively. Clover shoots were cut to 3 cm above the soil surface, except at the final harvest where the clover shoots were removed to the soil surface.

Chemical analyses

Clover shoots were digested and subsequently analysed for radioactive and non-radioactive P as described by McBeath et al. (2012). The specific activity of the fertiliser granules (MBq mg^{-1} water-soluble P – WSP) was corrected for WSP content of the SSP because the ^{33}P radiotracer would have only labelled the WSP fraction. The WSP component of the SSP was 88 % of the total P. The specific activity and recovery of fertiliser P in pasture components was calculated using the equations reported in McBeath et al. (2012).

Statistical analyses

All statistical analyses were carried out using R 3.0.2. A one-way analysis of variance (ANOVA) and orthogonal contrasts was used to compare treatment means at the $P < 0.05$ level of significance.

Results

Cumulative biomass removal and P uptake into clover shoots for the fertilised treatments was higher than in the unfertilised control at both field sites (Table 2). At the Ginninderra field site, cumulative biomass removal and P uptake into clover shoots for the early-season surface application was not significantly different to that of the early-season deep SSP application but was higher than the mid-season surface (Table 2). At the Inman Valley field site, cumulative biomass removal of clover shoots for the early-season surface treatment was not different to that of the early-season deep or mid-season surface applications of SSP at the Inman Valley field site (Table 2).

The recovery of fertiliser P in clover shoots was up to 42 % in the year of application (Table 2). In general, the recovery of fertiliser P in clover shoots at both sites was highest (~ 40 %) when fertiliser P was applied to the soil surface at early-season compared to that at depth or at mid-season to the soil surface (Table 2). However, at the Ginninderra site, the recovery of fertiliser P in clover shoots for the early-season surface treatment was not significantly different to that of the early-season deep treatment (Table 2).

Table 2. Cumulative biomass removal (t DM ha^{-1} equivalent), clover P uptake (kg P ha^{-1} equivalent), and recovery of fertiliser P (as a % of applied ^{33}P-labelled SSP) for clover shoots (> 0 cm above the soil surface) at the Ginninderra and Inman Valley field sites. Values in parentheses are standard errors.

Field site	Treatments Timing of fertiliser P[A]	Placement of fertiliser P[B]	Cumulative biomass (t DM ha^{-1})	Cumulative P uptake (kg P ha^{-1})	Recovery of fertiliser P (as a % of applied)
Ginninderra	Early-season	Surface	14.8 (0.7)	17.9 (0.6)	38.4 (2.1)
	Early-season	Deep	14.3 (0.3)	17.7 (0.6)	40.0 (1.5)
	Mid-season	Surface	11.1 (0.4)	13.7 (0.6)	28.5 (0.5)
	Nil	Nil	8.0 (0.4)	7.0 (0.8)	
Inman Valley	Early-season	Surface	11.3 (0.3)	25.5 (0.7)	42.4 (1.1)
	Early-season	Deep	9.5 (0.6)	21.8 (0.8)	27.3 (2.3)
	Mid-season	Surface	11.4 (0.8)	28.3 (1.3)	28.6 (1.3)
	Nil	Nil	8.8 (0.7)	15.2 (0.8)	

[A]Fertiliser P was applied to clover pastures at early-season (late April for the Ginninderra field site and early June for the Inman Valley field site) or mid-season (late July and mid August, respectively). [B]Fertiliser P was applied to clover pastures on the soil surface (surface) or at 6 cm below the soil surface (deep).

Cumulative biomass removal was higher in clover shoots at the P1 and P2 levels of soil P fertility than at the P0 level of soil P fertility with the addition of SSP (Table 3). Cumulative biomass removal in clover shoots at the P1 level of soil P fertility was similar to that at the P2 level of soil P fertility (Table 3). However, the cumulative P uptake in clover shoots increased 2-fold from P0 to P1, and then slightly more at P3 (Table 3).

The highest recovery of fertiliser P in clover shoots (46 %) occurred at the P1 level of soil P fertility (Table 3).

Table 3. Cumulative biomass removal (t DM ha^{-1} equivalent), clover P uptake (kg P ha^{-1} equivalent), and recovery of fertiliser P (as a % of applied from the ^{33}P-labelled SSP) for clover shoots (> 0 cm above the soil surface) across three levels of soil P fertility at the Ginninderra field site. Fertiliser P was applied at early-season to the soil surface. Values in parentheses are standard errors.

Field site	Treatments[A] (early-season surface)	Cumulative biomass (t DM ha^{-1})	Cumulative P uptake (kg P ha^{-1})	Recovery of fertiliser P (as a % of applied)
Ginninderra	P0	15.3 (0.4)	19.9 (1.5)	40.3 (1.3)
	P1	18.0 (0.6)	41.7 (2.3)	45.5 (0.8)
	P2	20.5 (1.1)	51.9 (2.6)	42.5 (1.5)

[A]Initial levels of soil P fertility in the topsoil layer (0 – 10 cm) include: 1) P0, 4 – 6 Olsen P kg^{-1}; 2) P1, 10 – 15 Olsen P kg^{-1}, and 3) P2, 20 – 25 Olsen P kg^{-1}.

Discussion

Clover pastures responded to the application of ~ 20 kg P ha^{-1} as ^{33}P-labelled SSP at both sites. This was expected due to the low concentrations of soil test P in the soil. The rate of fertiliser P used in this experiment was chosen to supply enough P so that a clover response to fertiliser P would be observed, but also at a rate that would be considered 'plausible' to primary producers as part of their P fertiliser management. At the Ginninderra site, Simpson *et al*. (2010) reported that an application of ~ 40 kg P ha^{-1} would be needed to obtain optimum clover yield when applying P to pasture growing at the P0 level of soil P fertility.

In general, high recoveries of fertiliser P in clover shoots were found for the surface application of fertiliser P when applied at early-season for both sites, but also when fertiliser P was applied at depth for the Ginninderra site. This showed that a considerable proportion of the fertiliser P was taken up into herbage in the year of application for these treatments and at these sites. Recoveries of 40 – 45 % for the early-season surface treatments at the Ginninderra and Inman Valley field sites were at the upper end of those typically reported for arable crops (McBeath *et al*. 2012). Some of the reasons for this high level of fertiliser recovery may include: 1) the presence of an established root system, which was concentrated in the surface layer of the soil profile when the fertiliser P was added; 2) the majority of P within SSP was water soluble and available to plants; and; 3) fertiliser P was unlikely to become rapidly unavailable to plants over the growing season in soils of low to moderate sorption capacity. Similar recoveries of fertiliser P in clover shoots between early-season surface and early-season depth treatments at the Ginninderra site suggest the latter may be advantageous in some soils at the pasture rejuvenation phase to provide nutrients at a depth less prone to wetting and drying. However, the ability to maximise pasture production and fertiliser P recovery with surface applications is advantageous to primary producers for economic and operational reasons.

Interestingly, fertility management considered to be near-optimal for high production, also proved to be the most efficient in terms of direct recovery of P after fertiliser application.

Conclusion

Our results indicate that clover pastures have a relatively high capacity to recover fertiliser P. High recoveries of fertiliser P by clover pastures were generally found when fertiliser P was applied to the soil surface at early-season, although there was evidence at the Ginninderra field site that applications of fertiliser P at depth can be utilised at a similar efficiency. A key consequence of our findings is that the cause of low efficiency of P (P exported in products relative to P inputs) fertilization in pasture systems is only partially due to low direct uptake of fertilizer P by pasture species.

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Factors affecting pasture productivity in topographically variable landscapes – implications for pasture input management

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Abstract
Seventy-three sampling locations (38 on the north-aspect, 35 on the south-aspect) in a topographically variable landscape paddock on the Central Tablelands of NSW were monitored to determine the effect of soil chemical and physical parameters and botanical composition characteristics on pasture production. Stratification of sampling points into regions based on landscape features (aspect and position on slope) showed pasture production varied significantly between strata within the paddock. In some instances, the difference in production between strata was greater than between aspects and was attributable to a combination of soil physical (principally those associated with waterholding capacity) and botanical composition (legume content) factors. Exchangeable aluminium, while not identified as an indicator of pasture productivity in initial analysis, was the main determinant of production when only soil chemical parameters were considered. Exchangeable aluminium in association with ability of soil to hold moisture were found to strongly influence legume content. The results of this study indicate that greater consideration of a range of factors, other than soil available P, are required to determine pasture production potential in variable landscapes. Further, researchers and advisors need to be cognisant of such factors in determining optimum fertiliser application strategies in such landscapes to optimise pasture production, livestock production and economic return on investment. This is particularly important as concurrent studies at this site found that, despite deficiency of available phosphors at all sampling locations, only two regional strata were responsive to P-application. The study findings also highlight the insidious impact soil acidity and associated aluminium toxicity on pasture production in high rainfall regions of southern Australia.

Key words
Pasture production, soil acidity, variable landscapes

Introduction
Variable landscapes, where cropping is precluded due to topographic characteristics cover large areas of the medium and high rainfall regions of south-eastern Australia. Livestock are the predominant source of farm income in such areas. Proximity to major metropolitan areas and associated demand for 'lifestyle' farms result in relatively high land prices (Behrdent and Eppleston 2011). Land acquisition as a means for increasing production can be cost-prohibitive for full time commercial farmers. To remain viable, farmers need to increase productivity per unit of land.

Traditionally, superphosphate has been used to stimulate pasture production in the abovementioned regions. The predominant legume found through these areas has historically been subterranean clover (*Trifolium subterraneum*). However, changing climatic conditions, specifically less reliable autumn breaks and unreliable spring rainfall has resulted in lower legume frequency and this is likely to have been exacerbated by reduced superphosphate application since the mid 1970's (Wheeler 1986, Howieson *et al*. 2000). Historical fertiliser were generally undertaken in discrete areas of the landscape on either fully improved exotic sown pastures, or pastures containing high levels of exotic legumes. Many of these pastures have now reverted to a naturalised state (Garden *et al*. 2000). Historic fertiliser studies did not take account of differences in microclimate and soil conditions (physical and chemical), which are a feature of variable landscapes (Hackney 2009). In studies on the Central Tablelands and Monaro regions, Hackney (2009) reported only six out of twelve discrete locations in variable landscape studies were responsive to uniform application of superphosphate despite all having sub-optimal available Colwell available P. Subjectively, lack of response was attributed to differences in botanical composition, soil chemical parameters (other than P-availability) and soil physical conditions. The degree to which these parameters affected response could not be objectively quantified in that study which concentrated on discrete areas of the landscape.

Fertiliser is the highest management cost input in variable landscape regions. Optimising returns from such an input, requires application strategies which consider the productive capacity and ability of different landscape areas to respond to fertiliser application need to be developed. In order to develop such strategies, a better understanding of the factors driving pasture production in variable landscapes is needed. This paper describes an experiment undertaken in a variable landscape on the Central Tablelands of NSW to determine the effect of soil chemical and physical parameters and botanical composition factors on pasture production.

Materials and Methods

The study site (20 ha) was located on the Central Tablelands of NSW (34°01' S, 149°33'E), longterm average annual rainfall of 830 mm. Soil across the site was a Kurosol and had a native perennial grass base with microlaena (*Microlaena stipoides*) the most prevalent grass. Subterranean clover (*Trifolium subterraneum*) had been introduced to the site during the 1960's via aerial application. Capeweed (*Arctotheca calendula*), flatweed (*Hypochaeris radicata*) and sorrel (*Acetosella vulgaris*) were the most prolific broadleaf weeds encountered. The paddock was broadly described as having north and south facing slopes of approximately equal area and within each aspect, east and west-facing aspects were also present.

Permanent sampling locations (73) were established across the north and south aspects on a regular grid. At each sampling location, measurement of location slope, aspect orientation, collection of soil for chemical analysis (0-10 and 10-30 cm), and soil particle fraction > 2mm were taken (0-10 cm),and penetrometer resistance at field capacity was measured. In addition, at every alternate sampling location, total soil depth and coarse soil particle fraction (CPF) > 2mm (30-50 cm and 50-80 cm) was assessed. Pasture production was assessed via direct cutting and drying at 80°C for 48 hours. Botanical composition was assessed at herbage harvest at individual species level. For the purposes of analysis, species were then grouped into the categories of 'perennial grass', 'annual grass', 'broadleaf weed', 'subterranean clover', and'other naturalised legumes'. Previous site studies (Hackney 2009) had shown more than 60% of total annual herbage production at this site occurred in spring, and therefore production for this study was monitored from 1 September to 30 November 2003.

For the purpose of data analysis, sampling points were stratified into eight regions based on aspect and slope position giving localities north upper (NU), north-north (NN), north-west (NW), north-east (NE), south upper (SU), south-south (SS), south-west (SW) and south-east (SE). Such subdivision represented a probable strategic fencing strategy to minimse over- and under-grazing by livestock. To investigate the relative importance of soil chemical and physical parameters, and botanical frequency properties on herbage production, a regression tree was fitted using least squares in Systat 12 using all measured parameters from the 36 sampling points where soil was sampled to 80 cm. No more than 10 splits were permitted and terminal nodes had to contain 5 or more units. Minimum split and split proportions were set at 0.05. In subsequent analysis, soil pH, total cation exchange capacity (TCEC), Al as a percentage of total cation exchange capacity, available P, available S, available K and organic carbon were fitted as factors assessing relative importance of soil chemical attributes on herbage production.. The regression tree model reports a proportional reduction in error (PRE) which is analogous to r^2 fitted in a regression equation (Shalizi 2006).

Results

Inclusion of all measured parameters in the statistical analysis showed subterranean clover frequency and factors associated with soil water holding capacity were the main factors affecting pasture production (PRE=0.79) (Figure 1). Areas with low subterranean clover frequency (<28%) produced the least herbage. Most of these areas were located on the north-facing slope. In contrast, the most productive areas were located on the south-facing slope – either facing due south, south-east or upper south slope without a westerly influence. No soil chemical factors were identified as influencing herbage production when all factors were considered simultaneously. When only soil chemical factors were considered in a separate analysis, exchangeable aluminium, exchangeable sulphur and organic carbon were the major factors affecting production, but PRE in this case was only 0.53. Soil available P was not a factor affecting productivity in the analysis. In a separate regression tree analysis, soil depth, exchangeable aluminium and presence of other legumes were found to be the factors affecting subterranean clover frequency (PRE=0.73).

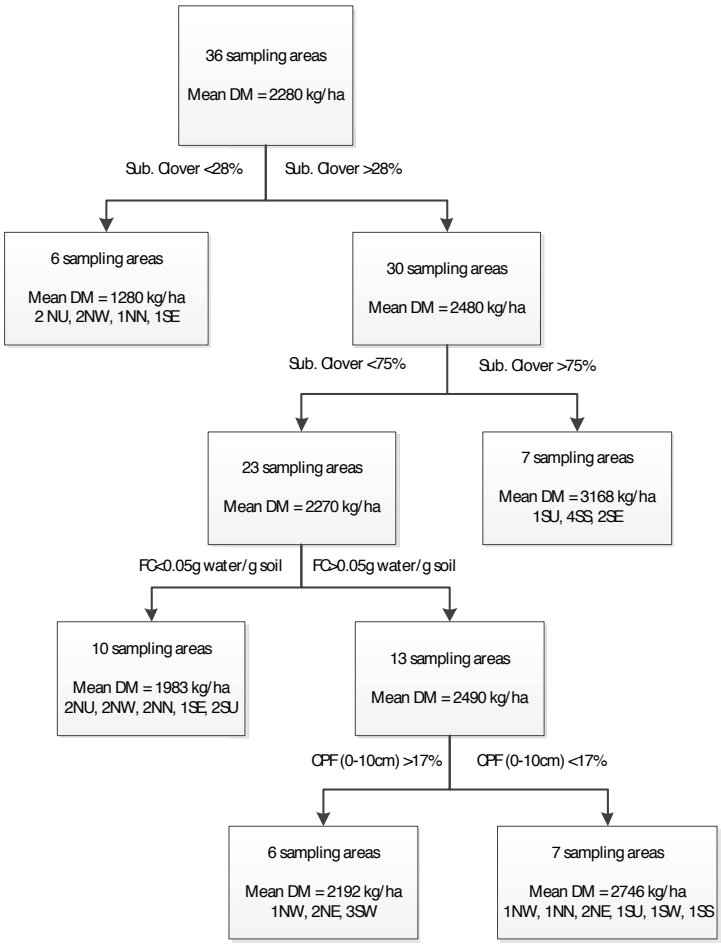

Figure 1. Spring herbage production as estimated from soil chemical and physical parameters and botanical composition for 36 sampling areas located in eight regions of a native perennial grass-based pasture at Burraga NSW in 2003. (Key: Sub clover = Subterranean clover, FC=field capacity, CPF= coarse particle fraction-the percentage of particles >2mm diameter. See the text for the system of classifying the sites according to aspect/slope).

Discussion

The influence of legume content on pasture productivity in combination with application of P-containing fertiliser has long been known (e.g. Whittet 1925). In this study, legume content was found to be a more important indicator of pasture production than was the level of P. Hackney (2009), in a concurrent study on this site, reported a response to application of superphosphate in only two of the eight strata despite all having sub-optimal levels of P. The results presented here should not imply that P-fertiliser is not an important consideration in influencing pasture production. Rather, it is likely that other factors are limiting the ability of resident pasture species to respond to applied P. For example, the ability of soil to hold sufficient moisture to respond to applied fertiliser, or the ability of plant roots to adsorb this P. Similar results have been reported by Zhang et al. (2005) in a New Zealand study where soil fertility, specifically available P and N, were found to be third and fourth tier determinants of production behind factors such as spring rainfall and slope (capacity to harvest moisture). These latter factors were found to be the main determinants of pasture production in variable landscapes.

When only soil chemical factors were used in the statistical analysis, exchangeable aluminium was found to be the major factor defining pasture production. The site used in the study was, in general, highly acidic with pH_{Ca} range of 4.2-4.6 across strata and associated exchangeable aluminium of 5-23%. Subterranean clover root growth, survival of associated rhizobia and therefore capacity to respond to applied P would be compromised under such conditions (Helyar 1991, Howieson *et al*. 2000). Highest productivity locations had the lowest coarse particle fraction and deepest soil (based on mean strata values). These sites also had highest subterranean clover content. Thus, subterranean clover plants in these strata were able to some extent to overcome the sub-optimal soil chemical conditions through access to higher moisture levels. Interestingly, the subterranean clover content required to achieve highest herbage production was over 75%. Recommendations for perennial grass-annual legume composition generally suggest legume content of

30-40% (Clements *et al*. 2000). It is probable in this study, that a higher percentage of legume was required to achieve greater production due to individual plant efficiency with respect to fixing N. Thus, a higher proportion of legume would be required to supply fixed nitrogen to non-leguminous pasture components. The suppressive effect of aluminium on subterranean clover production at this site was confirmed by the separate analysis where highest subterranean clover frequency was found in areas with lowest aluminium. This suggests exchangeable aluminium issues need to be addressed prior to the majority of the site having any capacity to respond to P-fertiliser application. However, other major limiting factors, such as soil depth, should not be ignored in an attempt to achieve an overall fertiliser response.

Lowest productivity areas were generally located on the north-facing slope and highest productivity on the south-facing slope. This is similar to findings of New Zealand researchers in variable landscapes (e.g. Radcliffe 1982). Hackney (2009) reported significantly shallower soil with a higher coarse particle fraction on the north compared to south-facing slope. Intermediate productivity areas were composed of sampling points from a range of strata indicating it can be difficult to define pasture productivity simply by locality. Radcliffe (1982) also reported variability within strata to be as great, or greater than that measured between aspects.

The implications of this study are important for allocation of inputs in variable landscapes. Greater appreciation of areas within a landscape to provide one of the fundamental resources for plant production – water, should be a primary consideration in estimating productive capacity. Legume content, too, is undisputedly a key factor affecting pasture production. However, the capacity of legumes to respond to management inputs, particularly fertiliser, may be limited by soil chemical properties and their interaction with root growth. While the legume plant may superficially appear to be healthy, as in this study, it is probable that root growth was stunted, thus rendering the plant less able to harvest nutrients and tolerate seasonal dry spells. Additionally, rhizobial survival and thus nitrogen fixation could be limited by soil acidity. This would then limit the potential for plants to respond to fertiliser addition. Consideration should also be given to optimising pasture composition in such landscapes. It may be that plants more able to tolerate soil acidity and infertility would be advantageous. Given the impact microclimate can have on grazing behaviour (Blackshaw 2003)in variable landscapes, the role of subdivisional fencing in conjunction with strategic, differential fertiliser application should not be ignored.

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Phosphorus efficient pastures: response of alternative legumes to fertiliser application

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Abstract
There is interest in pastures that require less phosphorus (P) fertilizer because P costs have risen. This objective requires legumes that yield as well as *Trifolium subterraneum*, but with lower critical P requirements (rate of fertilizer for 90% of maximum yield).

Two field sites were sown near Yass (autumn, 2012) and Bookham (2013). Yass was re-sown in 2013 to ensure establishment did not limit dry matter (DM) responses to P. The experiments included 12 pasture species (monocultures) at 6 P rates (0-80 kg P/ha, as triple superphosphate), (n=3 replicates). Maintenance P (0-31 kg P/ha) was applied at Yass in 2013. Lime and basal nutrients were applied to ensure only P and nitrogen were limiting. Legumes were inoculated with appropriate rhizobia. Herbage DM was determined in spring. Mitscherlich equations fitted to the DM data after Linear Mixed Model analysis were used to compare P requirements.

Some species proved unsuited to the soils and climate. Of those that established and grew well, only the grasses (*Phalaris aquatica, Dactylis glomerata*) and three legumes *(Ornithopus sativus* [pasture type], *T. incarnatum, T. purpureum* [forage types]) had DM yields equivalent to, or better than *T. subterraneum* whilst also having lower P-fertiliser requirements. *O. compressus* required less P, but did not yield as well. The critical *P requirement* of Medicago sativa was not reached over the P range used.

The experiments demonstrated that the P requirements of pasture legumes can differ. A few species yielded as well as *T. subterraneum* with lower critical *P requirements*.

Key words
Pasture legumes, critical phosphorus, *Ornithopus, Trifolium, serradella*, subterranean clover

Introduction
The phosphorus (P) balance efficiency of fertilised pastures in Australia is low with approximately 5 units of P applied as fertiliser to produce 1 unit of P in animal products (McLaughlin *et al*. 1992; Weaver and Wong 2011). The most common reason for low efficiency is accumulation of P in soil (McLaughlin *et al*. 2011) although other P losses (erosion, leaching, runoff) can also occur, particularly from sandy soils with low P sorption capacity. Pasture legumes that achieve equivalent yields at lower soil test P concentrations (i.e. lower critical P requirements) than *Trifolium subterraneum* (the most widely-used pasture legume) may reduce the amount of P fertiliser needed for productive pastures because fertilising soils to lower soil test P concentrations is expected to reduce the rate at which P accumulates in the soil (Simpson *et al*. 2014). Considerable resources have now been invested in the development of numerous alternative pasture legumes, mainly to address gaps in the areas where subterranean clover cannot be used reliably (Nichols *et al*. 2012). Little is known about the P requirements of these species. Here we report initial results from field experiments examining the growth during spring of a number of alternative legumes and two grasses in response to the application of P fertiliser. One objective of the work was to determine if any of the legumes could yield as well as *T. subterraneum* but at lower rates of applied P.

Methods
Field sites were sown near Yass (autumn, 2012) and at Burrinjuck near Bookham, (autumn, 2013) on the Tablelands of southern NSW. The initial choice of species was guided by evidence that a species may have a low P requirement; subsequent sowings were guided by field performance. Consequently, the alternative

legume now known to have the most promise (*Ornithopus sativus*), was first sown at the Burrinjuck site in 2013. Species were re-sown at Yass in 2013 to ensure establishment did not limit dry matter (DM) responses to P. Each experiment included 12 pasture species grown as monocultures with six rates of applied P (0, 15, 30, 45, 60 and 80 kg P/ha.); (n = 3 replicates). P was applied as triple superphosphate (20% P and 1.5% S). Maintenance P (0, 4, 10, 16, 24, 31 kg P/ha) was added to the six original P treatments, respectively, at Yass in autumn 2013. Lime and basal nutrients were applied to ensure only P and nitrogen were limiting. Legumes were inoculated with an appropriate rhizobium strain. Perennial grasses received a total of 80 kg/ha/yr of nitrogen in four equal applications during May, July, August, and October. Herbage DM yields were determined in spring.

Herbage yields were analysed using GenStat version 16.1 by applying Linear Mixed Models (LMM) with Rep+Row.Column as random effects. The yields generated from LMM at plot level were subsequently used to fit Mitscherlich equations for all species except Medicago sativa, where a linear fit was used. The relative critical P requirements of each species were estimated for each season and site as the rate of P application that corresponded with 90% of maximum herbage yield in spring.

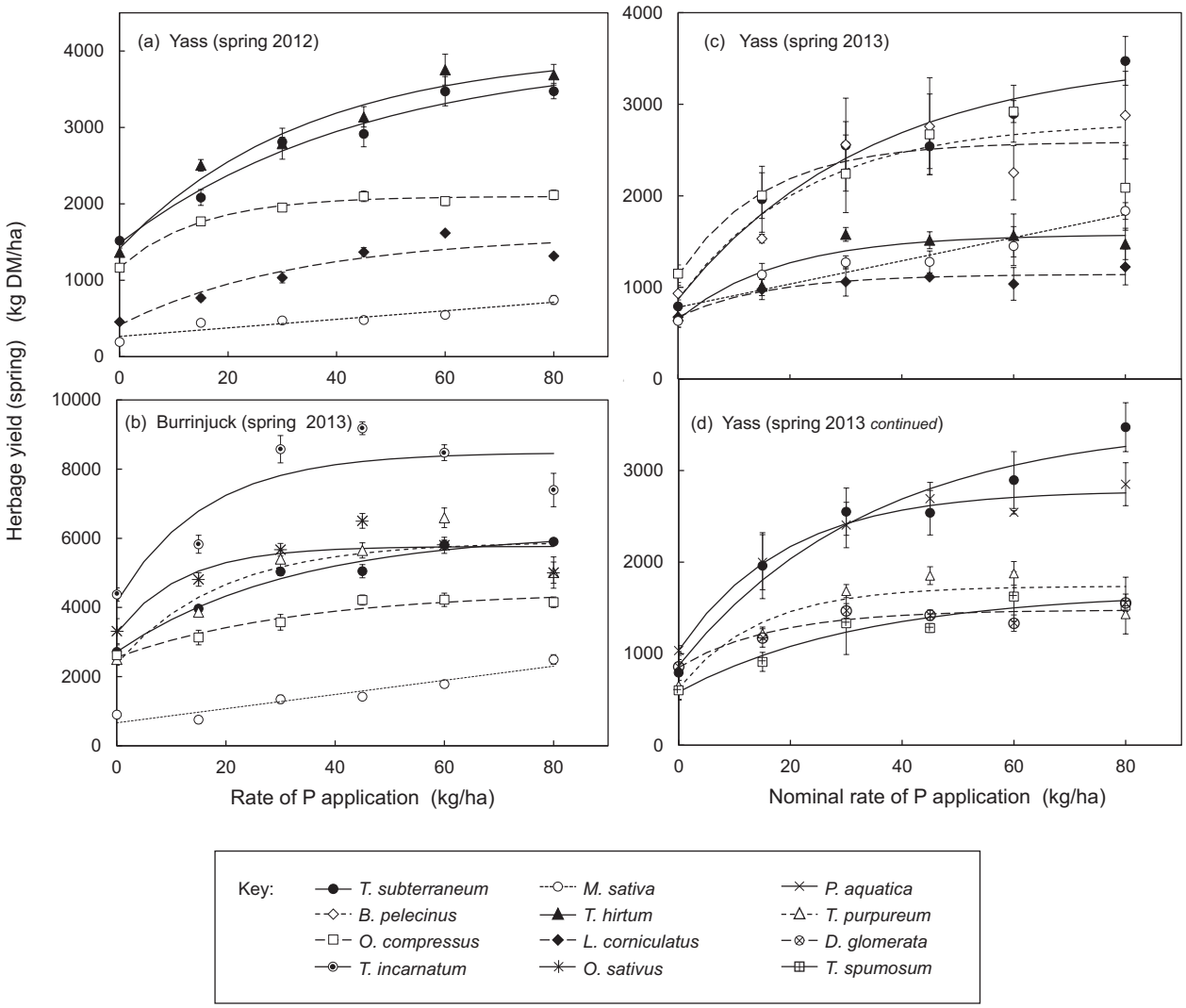

Figure 1. Yield of herbage DM grown in spring by species that had established adequately at the Yass (a, c and d) and Burrinjuck (b) sites. The result for *T. subterranean* is repeated in panels (c) and (d) for easy comparison with the other species. The Mitscherlich asymptotic function was fitted to the data using GenStat. For the year of establishment at each site, pasture yields are plotted relative to the P application rate. In the subsequent year (at Yass), soil P levels were topped up by adding a maintenance dressing of P and yields are plotted relative to the original P application rates, now designated (panels c and d) as the "nominal rate of P application". Error bars = 2xSE.

Result

Some of the pasture species that were sown proved to be poorly adapted to the Yass and Burrinjuck sites. For example: Bituminaria bituminosa ssp. abomarginata was susceptible to frost (sown at Yass only); Trifolium hirtum, in the year subsequent to its establishment, showed significant cold and waterlogging stress; Lotus corniculatus, Trifolium ambiguum and Trifolium tumens did not persist well over the dry summers (sown at Yass only); and Trifolium spumosum senesced prematurely during spring at Yass (2012 and 2013). The grasses were selectively grazed by wombats at Burrinjuck in early 2013 until additional fencing measures could be implemented. These issues reduced the opportunities to benchmark the critical P requirements of some of the species (Table 1). Some species (e.g. T. hirtum and T. purpureum) yielded as well as T. subterraneum in one season or at one site, but subsequently did not yield as well (Fig. 1).

The critical P requirement of a species can be yield dependant so two precautions were taken to minimise the chance of confounding yield or persistence issues with estimates of critical P requirements: (i) the species were oversown with fresh seed in the second year at Yass to ensure adequate densities of plants in all treatments and (ii) less credence was given to apparently-low critical P requirements that occurred in seasons when herbage yield was also significantly lower than that of T. subteraneum. When all of the potential comparisons from both sites were considered, four legumes and the two grasses appeared to have lower critical P requirement than T. subterraneum (Fig. 1, Table 1). Only one 'pasture type': Onithopus sativus had a lower critical P requirement whilst yielding as well as T. subterraneum. The critical P requirement of O. compressus was also consistently lower than that of T. subterraneum. However, it did not achieve equivalent yield to that of T. subterraneum. Two 'forage types' had lower critical P requirements and equivalent (T. purpureum) or higher (T. incarnatum) yields than T. subterraneum at Burrinjuck. Of these two, only T. purpureum was sown at Yass where it again had a low critical P requirement but did not yield as well as T. subterraneum. There has been no evidence that the maximum yield of Medicago sativa was achieved even at the highest soil P fertility levels in these experiments (~60 mg P/kg; Colwell 1963).

Table 1. Critical P application rates (kg P/ha) for 90% of maximum yield of pasture legumes and grasses grown in monocultures at Yass and Burrinjuck. It was not possible to estimate a critical P value for all species in some years or at both sites because some species had either failed to persist (due to pest/disease, frost, waterlogged soil) *(f)*; outcompeted by subterranean clover that germinated from the seed bank after or with the test species *(o)*; or was not sown at the site in that year *(ns)*. The critical P requirement of *Medicago sativa* was not reached over the P range used. Letters used in 'Relative P requirement column are L = low, M = medium, H = high.

Test species (cv.)	Yass 2012	Yass 2013#	Burrinjuck 2013	Relative P requirement	Yield relative to sub. clover
	Critical P application rate (kg P/ha)				(Yass district)
Dactylis glomerata (Porto)	*(f)*	25	*(f)*	L	lower
Phalaris aquatica (Advanced AT)	*(f)*	35	*(f)*	L	equal
Ornithopus sativus (Margurita)	*(ns)*	*(ns)*	18	L	equal
O. compressus (Santorini)	22	27	49	L	lower
Trifolium purpureum (Electra)	*(ns)*	27	34	L	lower
T. incarnatum (Dixie)	*(ns)*	*(ns)*	26	L	higher
T. subterraneum (Leura)	83	70	55	M	---
T. spumosum (Bartolo)	*(f)*	62	*(f)*	M	lower
Biserrula pelecinus (Casbah)	*(f,o)*	44	*(f)*	M	equal/lower*
Lotus corniculatus (LC07AUYF)	66	23	*(ns)*	L/M?	lower
T. hirtum (Hykon)	64	32	*(o)*	L/M?	equal/lower
Medicago sativa (SARDI 10)	---	---	---	H	---

critical P rate in this year at Yass is determined relative to the "nominal" P application rate applied during 2012; these rates were topped up with a maintenance dressing of P in 2013 (see Methods). * Lower based on failure in some years.

Discussion

Acclimation of species, or cultivars of species to farming districts is a critically important attribute for persistence and yield in pastures. The present observations are among the few available for some of the alternative legumes when grown in Tableland environments. They indicate that wider examination of species

performance should be considered if alternative legumes are to be promoted in these areas. The experiment demonstrated that there are at least some alternative pasture legumes that can yield as well as or higher than *T. subterraneum* with substantially lower critical P requirements. For example, the amount of P applied for equivalent yield by *O. sativus* at Burrinjuck was less than half that needed for *T. subterraneum*. However, it was also very clear that many of the alternative species were poorly suited to the cool, wet Southern Tableland's seasonal, or soil conditions. This, more than any other factor, restricted the comparisons of P requirements that could be made. The most promising species have now been grown for a further season at a wider range of sites confirming the observations made here. Soil samples are being tested for Olsen P and Colwell P to facilitate specification of critical soil test P levels.

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Phosphorus efficient pastures: variation in mycorrhizal colonisation of subterranean clover

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Abstract
Trifolium subterraneum (subterranean clover) is an important annual pasture legume in southern Australia. Development of more phosphorus (P)-efficient cultivars could improve the P balance of pastures. Subterranean clover hosts arbuscular mycorrhizal fungi (AMF). In glasshouse studies, AMF can enhance P uptake by subterranean clover. To examine whether subterranean clover cultivars differ in their levels of colonisation by AMF, a core collection of subterranean clover (97 lines, representing ~80% of genetic diversity in the species), and 42 cultivars were grown in a glasshouse in a low-P sandy soil with indigenous AMF. The soil was free of root diseases. The percentage of root length colonised by AMF, specific root length, average root diameter, shoot P concentration and shoot dry mass were measured. Variation in colonisation within the core and among the cultivars was similar, ~12-68% of root length. However, 41% of the core lines had > 40% of root length colonised compared with 24% of the cultivars. There was a positive linear correlation between colonisation level and shoot P concentration (r2=0.36, P<0.0001), but not shoot dry mass. Relationships between colonisation level and specific root length or average root diameter were weak. We conclude that potential may exist to develop subterranean clover lines with higher or lower colonisation by AMF. However, the benefits of doing so must first be established under field conditions.

Key words
Pasture legumes, mycorrhizal fungi, phosphorus, core collection

Introduction

Subterranean clover (*Trifolium subterraneum* L.) is the most widespread annual pasture legume in the temperate pastures of southern Australia (Nichols *et al*., 2012). For these pastures, substantial savings in P-fertiliser use, and improvements in fertiliser P-use efficiency, may be possible if the plant-extractable P concentrations in soil could be reduced, but herbage yield maintained (Simpson *et al*., 2014). Plants with lower P requirements typically have roots with improved ability to forage P from soil (Lynch, 2011; Richardson *et al*., 2011). There are a number of root traits that assist P foraging, including the level of colonisation by arbuscular mycorrhizal fungi (AMF).

When subterranean clover is grown in pasteurised soil in a glasshouse, inoculation with AMF promotes colonisation of the roots and reduces the plant's critical P requirement (the amount of P needed for near-maximum growth) as a result of increased P uptake from low P soil (Abbott and Robson, 1977; Schweiger *et al*., 1995). In the pastures of southern Australia, colonisation of subterranean clover roots by AMF is ubiquitous and a diverse population of AMF is likely to be present (Abbott and Robson, 1982; Ryan and Kirkegaard, 2012; Simpson *et al*., 2011).

To examine the feasibility of modifying the level of AM fungal colonisation in subterranean clover, we examined the percentage of root length colonised by AMF for 42 cultivars and for a further 97 lines which constitute the "core collection". The core collection was developed from the 10 000 lines of subterranean clover which are available in genetic resource centres worldwide and it is estimated to represent almost 80% of the total diversity of the species (Nichols *et al*., 2013).

Method

The experiment examined the 139 lines of subterranean clover; 97 lines core lines (Nichols *et al*., 2013) and an additional 42 cultivar lines which were included as they would already possess many agronomically favourable characters. Overall, there were 35 lines of ssp. *brachycalycinum*, 97 lines of ssp. *subterraneum*

and 7 lines of ssp. *yanninicum*. All seed originated from a single seed-bulking trial at Shenton Park Research Station (Floreat, Western Australia). The experiment was located in a glasshouse with a diurnal range of 5ºC to 24ºC. Sterilised pots (90 × 90 × 180 mm) were filled with 1 kg of an unpasteurised sandy-loam soil (8% clay, 82% sand, 10% silt). The soil had been collected from 0–40 cm depth in remnant forest, dried at 40ºC for one week and thoroughly mixed. It had low plant-extractable P (5.8 mg/kg, Colwell 1963) and a high P-buffering index (591) and was acidic (pH CaCl2 4.7). The soil was chosen as it was low in P, and a preliminary experiment had found subterranean clover grown in it was well colonised by AMF with no evidence of the major fungal root pathogens of subterranean clover. There were four replicate pots of each line. Seedlings were thinned to one per pot after one week. Phosphorus-free basal nutrients were applied. Pots were maintained at field capacity.

At harvest (week 6), root length (for calculation of specific root length) and average root diameter were measured after scanning fresh roots using the WinRHIZO 4.1 software package (Regent Instruments Inc., Quebec, Canada, 2000). The percentage of root length colonised by AMF was determined on a subsample of roots after staining in an ink/vinegar solution (Vierheilig *et al*., 1998). Shoots were dried at 60ºC for three days and weighed. Shoots were digested in a 3:1 HNO3:HClO4 solution and P measured by the yellow vanadomolybdate method.

Results

The percentage of root length colonised by AMF varied widely among the core lines from 15% to 55% (Fig. 1a). Colonisation in the cultivar lines covered a similar range, although one cultivar, Izmir, had 68% of root length colonised. The cultivars Izmir, Dalkeith (58%) and Bacchus Marsh (47%) were high colonisation outliers among the cultivar lines. Cultivars with very low colonisation, that is < 20% of root length colonised, were Dinninup, Trikkala, Rosedale, Larisa and Riverina.

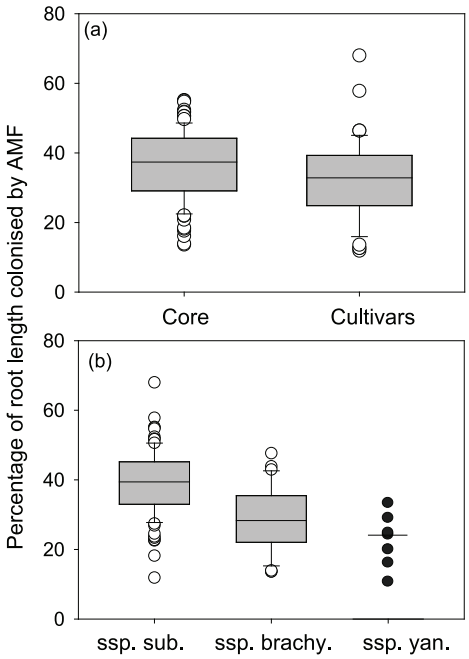

Figure 1. Box plots of the percentage of root length colonised by arbuscular mycorrhizal fungi (AMF) in T. subterraneum among: (a) core lines (n=97) and cultivar lines (n=42); and (b) ssp. *subterraneum* (sub.) (n=97), ssp. *brachycalycinum* (brachy.) (n=35) and ssp. *yanninicum* (yan.) (n=7). The boundaries of the box indicate the 25th and 75th percentiles, and the line within, the median. Whiskers indicate the 90th and 10th percentiles. Individual points are outliers. Subspecies yanninicum had insufficient data for a box plot and thus all data are graphed and the median shown.

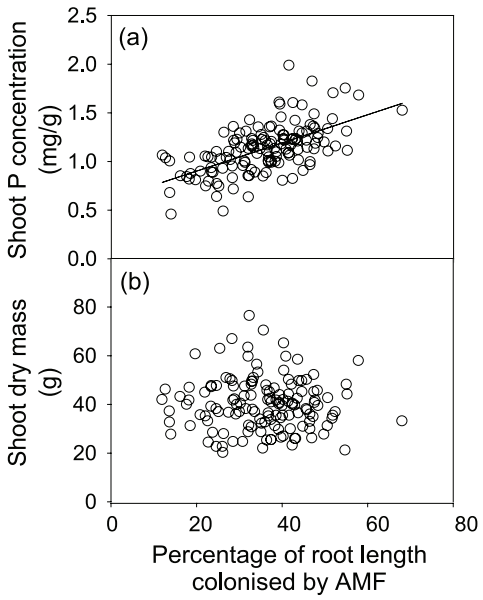

Figure 2. The correlation of (a) shoot P concentration and (b) shoot dry mass with the percentage of root length colonised by arbuscular mycorrhizal fungi (AMF) (n=139). For (a) r2=0.36, P<0.0001.

Overall, mean colonisation level was higher for the core lines than for the cultivar lines (core lines, 36.8% ± 1.0 s.e.; cultivar lines 32.8% ± 1.7 s.e; two-tailed t-test P=0.037). In addition, 41% of the core lines had >40% of root length colonised, while only 24% of the cultivar lines had >40% of root length colonised.

The percentage of root length colonised by AMF also varied among the three subspecies (Fig. 1b). Subspecies subterraneum was the most variable and included the 13 most highly colonised lines and the line with the lowest colonisation. Colonisation of ssp. *subterraneum* (39.2% ± 0.9 s.e.) was significantly higher than that of both ssp. *brachycalycinum* (28.5% ± 1.5 s.e.) and ssp. *yanninicum* (24.5% ± 3.0 s.e.) (two-tailed t-test P<0.0001). Colonisation did not differ between ssp. *brachycalycinum* and ssp. *yanninicum* (two-tailed t-test P>0.05). While no lines of ssp. *yanninicum* had >40% of root length colonised, 14% of ssp. *brachycalycinum* lines and 46% of ssp. *subterraneum* lines did so. Results for ssp. *yanninicum* may be influenced by the low number of lines representing this subspecies (n=7, all of which were cultivar lines).

Correlations between the percentage of root length colonised and shoot P concentration (Fig. 2a) and shoot dry mass (Fig. 2b) were investigated using the mean for each core line and cultivar line (i.e. n=139). There was a positive linear correlation between colonisation level and shoot P concentration, which ranged from 0.45–2.00 g/kg (Fig. 2a, r2=0.36, *P*<0.0001). There was also a positive linear correlation between the total length of colonised root and shoot P concentration (r2=0.35, *P*<0.0001; results not shown). There was no correlation between shoot dry mass and the percentage of root length colonised by AMF (Fig. 2b). Relationships between colonisation level and specific root length and average root diameter were significant, but as they accounted for relatively little of the variation in the data their practical significance is doubtful. Specific root length ranged from 85–175 m/g and had a positive correlation with the percentage of root length colonised by AMF (r2=0.14, *P*<0.0001). Average root diameter ranged from 0.295–0.424 mm and had negative linear correlation with the percentage of root length colonised by AMF (r2=0.13, P<0.0001).

Discussion

The differences in ranking among the subterranean clover subspecies were not anticipated and the reason is unknown; it could reflect differences in their ability to become colonised or be an indirect effect of differences in root morphology, root distribution or root growth rate. The comparison of the genotypes was made in a light textured, moderately acidic soil potentially more suited to the ssp. *subterraneum* and this may also have influenced the outcome. By comparison, ssp. *brachycalycinum* is noted for growth in neutral-alkaline soils (Nichols et al., 1996) and ssp. *yanninicum* prefers heavier, acidic soils (Nichols *et al*., 2013). However, it was evident that the ssp. *subterraneum* lines were not all highly colonised.

The slightly higher mean colonisation of the core lines (37% of root length) than the cultivar lines (33% of root length) is consistent with the recent meta-analysis of Lehmann et al. (2012) who found that ancestors, old cultivars and new cultivars of annual crop plants had a mean colonisation of 41%, 30% and 32%, respectively. However, other reports contradict this finding. An et al. (2010) found that the percentage of root length colonised among more than 200 lines of maize (*Zea mays* L.) was similar, perhaps even higher, for modern hybrids than older landraces. Leiser et al. (2015) found no effect of origin (landrace or researcher-bred) on colonisation levels in 187 sorghum (*Sorghum bicolor* L. Moench) lines from west and central Africa. Colonisation level was also found to have low heritability (Leiser et al., 2015).

Even if the heritability of colonisation level in subterranean clover is high, undertaking a breeding program targeting development of cultivars with higher levels of colonisation than current cultivars should be preceded by a robust study of the role of AMF in the growth and nutrition of subterranean clover under field conditions. There are a number of reasons for suggesting this approach. First, while we found a positive correlation between colonisation level and shoot P concentration, there was no correlation with shoot DM. Second, AMF have little impact on P uptake and growth of subterranean clover if plant-extractable-P (Colwell) is greater than ~20 mg/kg (Abbott and Robson, 1977; Schweiger et al., 1995). Third, several studies suggest little benefit for autumn-sown crops in southern Australia from high colonisation by AMF, even when under P limitation (Ryan and Kirkegaard, 2012). Similar studies are required for subterranean clover.

Conclusions

The percentage of root length colonised by AMF varied widely among core lines and cultivar lines of subterranean clover. However, it remains to be determined whether this variation has sufficient heritability to allow exploitation by breeders. The benefit to the growth and nutrition of subterranean clover of colonisation by AMF under field conditions in southern Australia also requires clarification. However, if higher, or lower, colonisation was shown to be desirable, the fact that cultivar lines had a similar range of colonisation to the core lines would mean that selection could occur from existing cultivars thereby encapsulating other agronomically-desirable characteristics such as disease resistance.

Acknowledgements

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Recovery of 15N urea fertiliser applied to wheat under different management strategies, in the High Rainfall Zone of south western Victoria

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Abstract

The fate of ^{15}N labelled urea applied to wheat cv. Bolac was studied at Hamilton (2012) and Tarrington (2013) on brown chromosol soils in the High Rainfall Zone of south western Victoria. Wheat was fertilised with ^{15}N labelled urea solution, equivalent to 100 kg N/ha, either deep banded 10 cm below the seed at sowing or topdressed with or without the nitrification inhibitor DMPP (3,4-*Dimethylpyrazole phosphate or* ENTEC®) at the first node growth stage. At physiological maturity, the recovery of ^{15}N in straw, grain and soil (40 to 60 cm depth) was assessed. At both sites, topdressing N resulted in significantly ($P<0.001$) greater recovery of applied N than deep banding. However, topdressing with DMPP did not significantly improve crop recovery of ^{15}N urea compared with untreated urea. Across both sites, between 76 and 84 % of the applied ^{15}N was recovered in the plant and soil at maturity when topdressed at first node, compared with 7 to 23 % when ^{15}N was deep banded. The poor recovery of deep banded ^{15}N appeared to result from winter waterlogging triggering gaseous or drainage losses before wheat reached peak growth and demand for N in spring. Despite, the poor recovery of deep banded ^{15}N, wheat grain yields were statistically the same as those topdressed with ^{15}N; the former treatment compensating for low fertiliser recovery by sourcing more N from the soil. Both sites had high concentrations of soil organic C (>3.1 %) and the potential for large rates of mineralisation.

Key words

Wheat, nitrogen, nitrification inhibitor, 3,4-dimethylpyrazole phosphate, urea, nitrogen recovery

Introduction

Nitrogen (N) fertiliser now constitutes the single largest variable cost for most grain growers, and so maximising N fertiliser uptake and avoiding wastage, is essential for increasing grower returns and reducing losses into the surrounding environment. In the High Rainfall Zone (HRZ) of south west Victoria, potential yield for wheat (*Triticum aestivum*) is around 10 t/ha, and high rates of N fertiliser may be required to meet expected crop demand arising from the high yield potential. However, recent research has highlighted large losses of N as nitrous oxide (N_2O) into the atmosphere (Harris *et al*. 2013) from soils in the region, which are prone to waterlogging, making it more difficult to judge the appropriate N fertiliser management. Cropping soils in the region are characterised by strong textual changes between the topsoil and subsoil, and in combination with a winter dominant rainfall pattern, can experience prolonged periods of transient winter waterlogging (MacEwan *et al*. 1992).

Anderson *et al*. (1992) suggested that early sown, well fertilised, dense vigorous crops growing on textual contrast soils prone to waterlogging were an important strategy for achieving high yielding crops. However, peak demand for N occurs during the stem extension phase of crop growth (Angus 2001) in late winter to early spring, and N supply during this period might encourage greater crop recovery of applied N. Another potential strategy for improving N fertiliser recovery in waterlogged soil, might be through the use of nitrification inhibitors such as *DMPP coated to conventional urea* (ENTEC®). Nitrification inhibitors are designed to delay the oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) (Zerulla *et al*. 2001) thus keeping N in a form less prone to escape (Pfab *et al*. 2012) and potentially greater retention for crop uptake. In this paper we study the fate of ^{15}N labelled urea, either deep banded 10 cm below the seed at sowing or topdressed with or without DMPP at the commencement of stem extension, to determine the appropriate method for maximising wheat N uptake and minimising losses under waterlogged conditions.

Methods

Two replicated field experiments were conducted; one at Hamilton (142°07'E 37°82'S) in 2012 and another at Tarrington (142°10'E 37°79'S) in 2013, in south west Victoria on Ferric-Eutrophic Brown Chromosol

soil. The Hamilton experiment was conducted on 1.35 m wide raised beds, while the Tarrington experiment on a conventionally flat site with a slight slope (between 1 and 2% grade). Both experiments comprised a completely randomised block design with four treatments replicated five times. Treatments included a 0N experimental control, and three other treatments where ^{15}N labelled urea (100 kg N/ha) was either deep banded at a depth of 10 cm below the intended seeding depth the day before planting (DB100N@Z00), topdressed at the first node (Z31) growth stage (TD100N@Z31); or treated with DMPP and also topdressed at Z31 (DMPP100N@Z31). Treatments were imposed to microplots comprising two rows of wheat planted 15 cm apart within rectangular metal boxes (30 cm wide by 53 cm long) with open bottoms and tops, inserted to a depth of 20 cm into the soil, at the beginning of the growing season. ^{15}N-enriched (10 % a.e.) urea solution was pipetted at 10 mL or 1.590 g per microplot to the fertilised treatments; with DMPP (1% w/w) mixed thoroughly with the ^{15}N-enriched solution before applying the DMPP100N@Z31 treatment. Microplots were installed in the 0N treatment to quantify the natural enrichment of ^{15}N in the crop and soil. All treatments received a basal application of 15 kg of P/ha at sowing when wheat cv. Bolac was sown on 31 May 2012 at the Hamilton site, and 9 May 2013 at the Tarrington site. Fertiliser was topdressed on 10 September 2012 and 19 August 2013 at the respective Hamilton and Tarrington sites.

Before experimentation, five deep soil cores (internal diameter 42 mm) were randomly collected from each replicate of the Hamilton and Tarrington sites. Cores were divided into 10 cm increments to 40 cm depth, and thereafter in 20 cm increments. Four of the five cores collected were combined for each layer within each replicate. Samples were then oven dried at 40°C for 48 h and passed through a 2 mm sieve in preparation for chemical analysis. The remaining core collected from each replicate was weighed and oven dried at 105°C for 48 h and weighed again to determine bulk density.

At physiological maturity plants from within each microplot were cut at ground level and dried at 60°C until constant weight reached, then threshed to separate grain from straw, and subsampled for analysis. Following harvest the entire 0-10 and 10-20 cm soil layers were excavated, and 6 cores (internal diameter 42 mm) randomly taken by hydraulic auger from the 20-40 cm layer at both sites, and the 40-60 cm layer at the Tarrington site, within each microplot. Cores were combined for each layer within each microplot. All soil samples were weighed, then a subsample retained weighed and dried at 105°C until a constant weight was reached before being reweighed to determine soil water content. Another subsample from each layer was dried at 40°C until constant weight reached for analysis. Plant and soil subsamples were finely ground to <100 µm in preparation for subsequent analysis. Plant and soil samples were analysed for total N and ^{15}N enrichment by a continuous flow mass spectrometer. The percentage of N derived from fertiliser was determined by dividing the atom% ^{15}N excess of total N in the plant, by the atom% ^{15}N excess of N in the fertiliser. The percentage recovery of ^{15}N fertiliser in the crop and soil were calculated using the formulas of Hauck and Bremner (1976). Treatment differences were tested using analysis of variance (ANOVA).

Results

Before imposing treatments there was 297 and 116 kg of soil NO_3^- /ha stored in the top 100 cm of the soil profile at the respective Hamilton and Tarrington sites. At the Hamilton site, 90% of the NO_3^- was stored in the top 40 cm of the profile compared with 48% at the Tarrington site (Figure 1a). At both sites soil organic carbon (C) concentrations declined with depth (Figure 1b).

Deep banding of ^{15}N labelled urea at sowing (DB100N@Z00) resulted in significantly (P<0.001) lower amounts of N fertiliser recovery compared with topdressing at Z31, at both the Hamilton and Tarrington sites (Figure 2). Adding DMPP did not significantly improve ^{15}N urea recovery in the crop, when topdressed at Z31, at both sites (Figure 2). Total recovery of N fertiliser in the soil at plant maturity was also significantly (P<0.001) lower under the DB100N@Z00 treatment in comparison with the topdressed treatments, with only 4.3 and 10.5% of the N initially applied recovered at the respective Hamilton and Tarrington sites. The differences were confined to the 0-20 cm soil layers at the Hamilton site and the 0-10 cm layer at the Tarrington site. The very low recovery of ^{15}N labelled urea in the DB100N@Z00 treatment resulted in significantly (P<0.001) higher losses of applied N, compared with the topdressed treatments, with 93.1 % of the N fertiliser unaccounted for in the soil and crop at the Hamilton site, and 77.1 % unaccounted for at the Tarrington site. Fertiliser management did not alter either crop biomass nor grain yield at either sites

(data not shown), with wheat yielding 16,660 (±959) kg DM/ha and 6,735 (±552) kg/ha of grain at Hamilton and 12,882 (±580) kg DM/ha and 6,052 (±275) kg/ha of grain at the Tarrington site, averaged across all treatments.

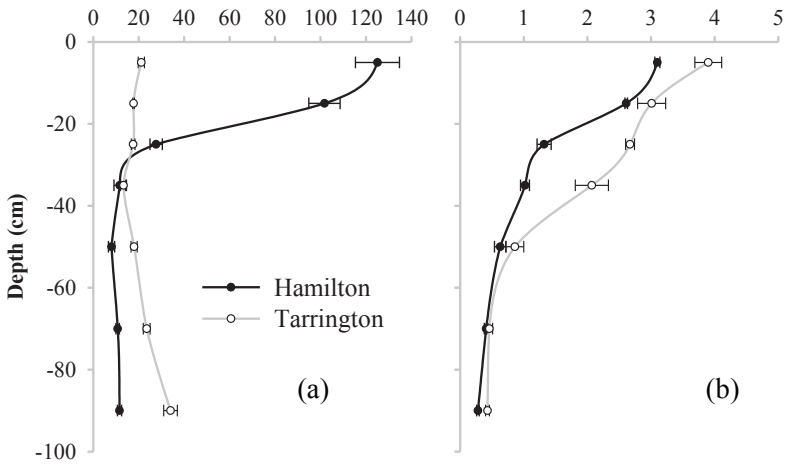

Fig 1. Distribution of soil NO_3^- (kg/ha) to 100 cm depth in autumn, before seeding at Hamilton (a) and Tarrington (b) in south west Victoria. Bars ±SE (n=5).

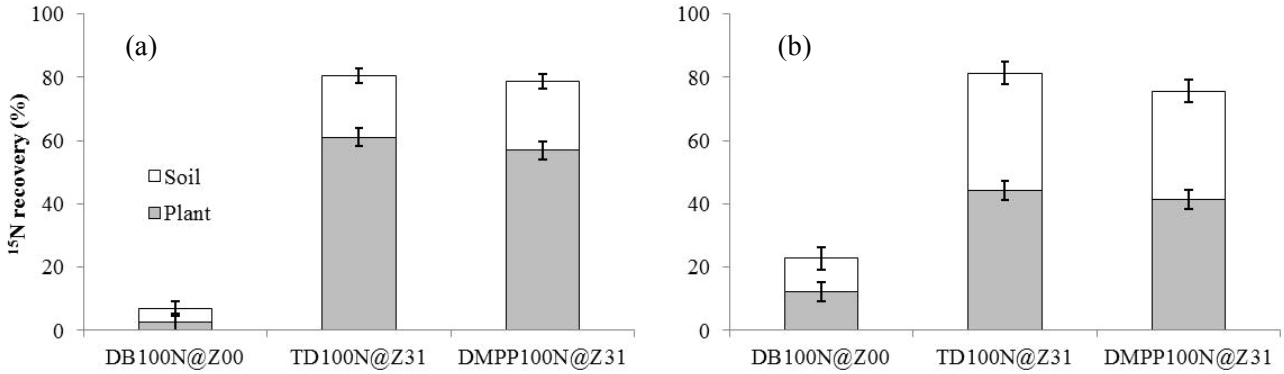

Fig 2. Percent ^{15}N urea recovery in the plant (grain and straw) and soil, for respective treatments at the Hamilton (a) and Tarrington (b) experimental sites. Bars are least significant difference (*P*<0.001).

Discussion

Deep banding high rates of ^{15}N labelled urea early in the growing season caused a temporal mismatch between supply and peak demand for N by the wheat, resulting in poor recovery of fertiliser by the crop and greater opportunities for loss of N from the soil: plant system. Crop recovery of topdressed urea applied in our studies were close to the range of 20 to 56% previously reported by other collective studies (Fillery and McInnes 1992). However, the crop recovery of deep banded urea at sowing was well below the 44 to 49% previously reported by Fillery and McInnes (1992) and Adjetey *et al*. (1999). Both sites in our study experienced above average winter rainfall leading to both surface and subsurface waterlogging and possible drainage losses. Furthermore, high concentrations of soil organic C in the top 40 cm of the profile at both sites (Figure 1b), may have provided desirable habitat for denitrifying microbial communities (Clark *et al*. 2012). Both sites were cultivated prior to sowing and research elsewhere has shown greater nitrous oxide emissions associated with deep N placement in recently cultivated soil, compared with shallow N placement under high soil moisture (Drury *et al*. 2006). While our data showed no evidence of leaching below 20cm, subsoil lateral flow along the top of the subsoil may have been another avenue for escape, especially at the Hamilton site where microplots were installed on raised beds, designed to drain water laterally.

Crop recovery of ^{15}N labelled urea was not enhanced by the use of DMPP, implying no increased retention of the applied N for crop uptake or improved yield over conventional urea. While other studies have shown a greater retention of NH_4^- in response to the application of DMPP (Weiske *et al*. 2001; Pfab *et al*. 2012), few have demonstrated improved plant N uptake and yield. Soares *et al*. (2012) reported the nitrification inhibitor dicyandiamide (DCD) coated to urea and applied to the soil surface, increased ammonia (NH_3) volatilisation

by 5-16%, resulting from a longer retention period of elevated soil ammonium and soil pH concentrations, compared with urea. Although our study involved the use of DMPP, we speculate that perhaps higher NH_3 losses may have resulted in no greater net retention of N for crop uptake compared with urea, and therefore no improvement in yield over the use of conventional urea.

Wheat growing on top of the deep banded treatment at the Hamilton and Tarrington sites predominantly sourced N requirements from the soil. In addition to stored soil N at the beginning of the growing season (Figure 1a), it's also likely that a significant proportion of crop N uptake was sourced from in-crop N mineralisation (Angus *et al*. 2001), especially at the Tarrington site. Although mineralisation was not measured in our study, applying the Baldock (2003) model, accounting for high organic C concentrations at the Hamilton and Tarrington sites, we estimate that between 99 and 195 kg N/ha may have mineralised over the respective growing seasons. The high in-crop mineralisation potential at both sites, helps partly explain the lack of grain yield response to N application irrespective of N management strategy. Clearly, wheat growing in the deep banded treatment was able to compensate for the poor recovery of ^{15}N urea, by sourcing larger amounts of N from the soil over the growing season.

Acknowledgements
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Nitrogen use efficiency in summer sorghum grown on clay soils

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Abstract
Nitrogen fertilizer inputs dominate the fertilizer budget of grain sorghum growers in northern Australia, so optimizing use efficiency and minimizing losses are a primary agronomic objective. We report results from three experiments in southern Queensland sown on contrasting soil types and with contrasting rotation histories in the 2012-2013 summer season. Experiments were designed to quantify the response of grain sorghum to rates of N fertilizer applied as urea. Labelled ^{15}N fertilizer was applied in microplots to determine the fate of applied N, while nitrous oxide (N_2O) emissions were continuously monitored at Kingaroy (grass or legume ley histories) and Kingsthorpe (continuous grain cropping). Nitrous oxide is a useful indicator of gaseous N losses. Crops at all sites responded strongly to fertilizer N applications, with yields of unfertilized treatments ranging from 17% to 52% of N-unlimited potential. Maximum yields ranged from 4500 (Kupunn) to 5450 (Kingaroy) and 8010 (Kingsthorpe) kg/ha. Agronomic efficiency (kg additional grain produced/ kg fertilizer N applied) at the optimum N rate on the Vertosol sites was 23 (80 N, Kupunn) to 25 (160N, Kingsthorpe), but 40-42 on the Ferrosols at Kingaroy (70-100N). Cumulative N_2O emissions ranged from 0.44% (Kingaroy legume) to 0.93% (Kingsthorpe) and 1.15% (Kingaroy grass) of the optimum fertilizer N rate at each site, with greatest emissions from the Vertosol at Kingsthorpe. The similarity in N_2O emissions factors between Kingaroy and Kingsthorpe contrasted markedly with the recovery of applied fertilizer N in plant and soil. Apparent losses of fertilizer N ranged from 0-5% (Ferrosols at Kingaroy) to 40-48% (Vertosols at Kupunn and Kingsthorpe). The greater losses on the Vertosols were attributed to denitrification losses and illustrate the greater risks of N losses in these soils in wet seasonal conditions.

Key words
Nitrogen fertilizer, grain sorghum, NUE, denitrification, ^{15}N balance

Introduction

Grain production in north-eastern Australia (the Northern Grains Region, NGR) predominantly is on Vertosols which have a high soil moisture storage potential. The cropping system is opportunistic, with either summer or winter crops being sown once adequate stored moisture is available. Rapid increases in yield potential and agronomic management systems for grain sorghum (Sorghum bicolor L.) have seen this crop become increasingly dominant in the rotation. At the same time there has been a decrease in soil organic matter status and mineralisable N reserves in the cropped Vertosols (Dalal and Probert 1997) that has resulted in an increasing fertilizer N demand to meet water-limited yield potential. This is illustrated in the contrasting N requirements for 'new' (<10 years cropping history) and 'old' (>40 years cropping history) cropping soils reported by Lester et al. (2008), with the combined effect of increased yield potentials and decreasing native N supply resulting in fertilizer N application rates increasing from negligible to >100 kg N/ha/year in some higher yielding areas.

Fertilizer costs often exceed 30% of the total variable costs in a cropping season, with nitrogen (N) the dominant fertilizer input for grain crops. It is therefore imperative that growers are able to optimise fertilizer N use efficiency (NUE), both in terms of crop recovery of applied N and conversion of that N into improved grain yields. One of the factors than can reduce fertilizer recovery and subsequent NUE is gaseous losses through the process of denitrification – the reduction of soil NO_3-N to N_2O and N_2 which are subsequently lost to the atmosphere. These losses are favoured when soil NO_3-N concentrations are high, there are sufficient levels of organic carbon and there is a deficit of oxygen such as would occur when clay soils become waterlogged. The summer sorghum crop in the NGR is typically sown into soil profiles that already are wet, at the beginning of the summer rainy season with N fertilizer typically applied in advance of sowing. The variable rainfall patterns preclude in-season N applications in most rainfed areas, so the full complement of N to meet expected crop demand is available in the soil well in advance of crop N demand – a situation that is high risk for denitrification losses and inefficient use of fertilizer N.

This study explored the fertilizer N response of sorghum crops at three locations in southern Queensland, determining crop N recovery and the efficiency with which fertilizer N was converted into grain yield. It also monitored N_2O emissions continuously or periodically, depending on site, as an indicator of denitrification events, and used ^{15}N recoveries in soils and plants to indicate the fate of applied N fertilizer and the extent of N losses.

Methods

Field experiments were conducted in 2012-2013 on research stations in the South Burnett (Kingaroy) and near Toowoomba (Kingsthorpe), as well as in a commercial sorghum field at Kupunn, in the central Darling Downs. The soil types were a Brown Ferrosol (Kingaroy) and a Black (Kingsthorpe) and Grey (Kupunn) Vertosol, respectively. The Kupunn crop was sown in mid-October 2012 following a short fallow and a previous sorghum crop in 2011-2012 and was grown solely rain-fed; Kingsthorpe was sown on 26 November, after a short duration winter forage crop of barley removed for hay; however Kingaroy, which was sown on 10 December, was sown onto contrasting grass or legume ley pasture histories (detailed in Migliorati et al. 2015). The different rotations were continued until spring of 2012 and although supplementary irrigation was used, the soil profile in the 2012-2013 planting window was quite dry, necessitating a 20 mm irrigation to allow planting and 100 mm split over three subsequent irrigation events until mid-January to ensure good crop establishment and tillering. After mid-January the crop was also solely reliant on rainfall.

The 2012-2013 season was unusually wet, with in-season rainfall totalling 360 mm (Kupunn), 392 mm (Kingsthorpe) and 770 mm (Kingaroy), respectively, although heavy rainfall over a 2-3 day period in late January 2013 contributed 30-45% of the seasonal total and, in the case of Kupunn, lead to a 4-5 day period of inundation from floodwater.

Nitrogen fertilizer was applied as banded urea either 25 d prior to planting (Kupunn), at planting (Kingsthorpe) or split between planting and a side dressing application 4 weeks after planting (Kingaroy). Rates of application were 0, 70, 100 and 120 kg N/ha at Kingaroy, 0, 20, 40, 60, 80, 120 and 160 kg N/ha at Kupunn and 0, 70, 140, 280 and 420 kg N/ha at Kingsthorpe. Urea labelled with ^{15}N (10% enrichment) was applied in solution in micro plots embedded within a subset of the N rate main plots in each field trial at the time of fertilizer application.

During the season, N_2O emissions were monitored using a fully automated greenhouse gas measuring system at both Kingaroy and Kingsthorpe, providing a long-term high temporal resolution dataset to quantify cumulative N_2O emissions during the growing season and the subsequent fallow. Twelve automated sampling chambers were deployed in each experiment, with chambers placed adjacent to the crop row and encompassing the fertilizer band in the targeted N rates and in a similar position in the 0N treatment to provide quantitation of background N_2O emissions. The measuring system was deployed immediately after planting and temporarily withdrawn to permit farming operations (side dressing, harvest, post-harvest cultivations) as appropriate. At Kupunn, periodic measurements were made using manual chambers deployed on band and inter-band positions, with measurements used as a relative assessment of emissions in different N rates at different times after fertilizer application.

Biomass samples were collected at physiological maturity, dried and analysed for total N content, with fertilizer N recovery calculated as the difference between the N content of the unfertilized Control and the respective N rate treatments. Grain yields were determined after the crop was sprayed with glyphosate at Kupunn, but directly harvested at Kingsthorpe and Kingaroy, and grain N concentration was determined to quantify net N balance of the different N rates. In the case of the ^{15}N microplots, plant samples (including roots and crowns in the top 10-15 cm) were collected at harvest and separated into above (grain and stover) and below ground biomass before analysis to quantify fertilizer N recovery.

Soil samples were collected to 100-120 cm in both the ^{15}N microplots and selected treatments in the main agronomy trial immediately after harvest. In the agronomy trial these were used to determine residual mineral N and in the ^{15}N trial both mineral N and total N determinations were made. There was no evidence of significant leaching of ^{15}N fertilizer deeper than 50 cm (Kingsthorpe) – 70 cm (Kingaroy and Kupunn). The fate of applied fertilizer N was therefore calculated as the sum of labelled ^{15}N recovered in the soil and plant pools, with the difference between the applied N and N recovered at harvest determined as lost via gaseous N loss pathways.

Results

Crop response to applied N

Crops at all sites responded strongly to fertilizer N applications. Yields in the unfertilized treatments were lowest after the grass ley history at Kingaroy (940 kg/ha), but ranged between 2500 and 3700 kg/ha at the other locations (Table 1). These yields represented 17% (Kingaroy, grass ley history) to 52% (Kupunn, short fallow after sorghum) of the N-unlimited yield potential (Y_{max}) across the sites, with differences in Y_{max} related to low plant populations (Kupunn) and excessively wet and overcast conditions at critical growth stages (Kingaroy). There were relatively small differences in mineral N contents in the soil profile prior to planting (50-70 kg N/ha to 90cm), but much larger differences in crop N accumulation in above ground biomass in the unfertilized treatments (25-113 kg N/ha), suggesting significant differences in net N mineralization and crop acquisition during the growing season.

The fertilizer N rate at which yields closely approximated 90% of the N-unlimited yield potential ($Y_{90\%}$) was similar at Kupunn and the Kingaroy sites (70-100 kg N/ha), but was higher at Kingsthorpe (160 kg N/ha). This was consistent with the differences in yield potentials (5200-5400 kg/ha vs 8010 kg/ha), and hence crop N demand. Agronomic efficiency (kg additional grain produced/kg applied N fertilizer) at the N rate resulting in $Y_{90\%}$ was 23 (80 N, Kupunn) to 25 (160N, Kingsthorpe) but 40-42 at Kingaroy (70-100N), with the former suggesting much more efficient use of applied N on the Ferrosol soils at Kingaroy.

Table 1. Agronomic data describing the fertilizer N response at Kingaroy (grass and legume ley histories), Kupunn and Kingsthorpe in 2012/13.

	Kingaroy (grass)	Kingaroy (legume)	Kupunn	Kingsthorpe
Y_0 (kg/ha)	940	2520	2700	3680
Y_{max} (kg/ha)	5440	5440	5220	8010
N rate for $Y_{90\%}$	100	70	80	160
AgronEff $_{Y90}$ (AE_{90}; kg additional grain/kg N applied)	42.5	39.6	28.7	25.9

Cumulative N_2O emissions

Nitrous oxide emissions for the sorghum growing season and the immediate period post-harvest are shown in Figure 1 for Kingaroy and Kingsthorpe, with the contribution of emissions resulting from fertilizer application clearly evident at both locations relative to the unfertilized controls. What is also evident is the episodic nature of emissions, especially in response to significant rainfall events producing waterlogging (e.g. late Jan-early Feb 2103) and also to irrigation events earlier in the season at Kingaroy.

The net effect of fertilizer application (i.e. discounting emissions from unfertilized treatments) was higher on the Vertosol at Kingsthorpe (2150 ± 112 g N_2O-N/ha) than at Kingaroy on the Ferrosol, despite much lower seasonal rainfall – especially in the event in late January 2013. However, at Kingaroy there was a significant difference between grass and legume ley histories, with the lower emissions in the legume history than the grass (413 v 1267 g N_2O-N/ha, respectively). When the Kingaroy and Kingsthorpe sites with automated monitoring were compared on the basis of N_2O emissions intensity (kg N_2O-N/t grain yield), the legume ley treatment at Kingaroy (0.12 kg N_2O-N/t) was less than half that recorded in the grass ley at Kingaroy or on the site at Kingsthorpe (0.29 and 0.30 kg N_2O-N/t, respectively).

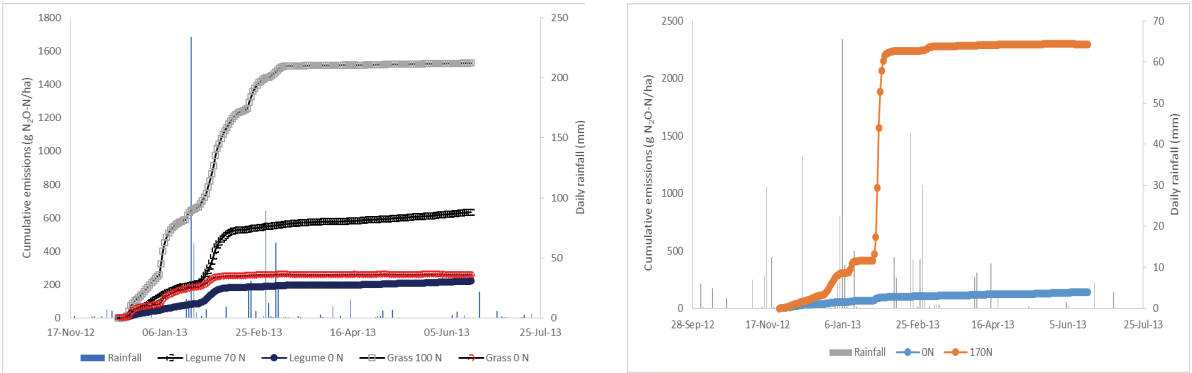

Figure 1 Cumulative N_2O emissions for (a) Kingaroy and (b) Kingsthorpe for the 2012/13 growing season. Daily rainfall is shown for each location.

Fate of applied N fertilizer

Soil and plant samples taken from ^{15}N microplots at maturity in the N rates at which yields were ca. 90% of Y_{max} indicated strong contrasts between the ley histories on the Ferrosols and the two trials on the Vertosols in terms of fertilizer recovery in crop biomass (60-80% on the Ferrosols v's ~40% on each of the Vertosols) and the residual fertilizer N in the soil profile (30-35% on the Ferrosols v's 10-20% in the Vertosols). Collectively, the data (Table 2) suggest that most of the applied N was accounted for in the Ferrosol treatments (losses of 0-5%), which was consistent with findings of Migliorati et al. (2014). However losses equivalent to 40% (Kupunn) to 48% (Kingsthorpe) of the applied N were recorded in the Vertosols. There was no evidence of leaching of fertilizer ^{15}N to the 100cm depth of soil sampling, confirming that most of the unaccounted ^{15}N was lost to denitrification.

Table 2. Recovery of applied fertilizer N from ^{15}N labelled urea (kg fertilizer N/ha) in the 2012/13 season. Measured ^{15}N is partitioned between plant parts and soil, with unaccounted N deemed to be lost to the environment. Data are presented as means (± SE).

	Brown Ferrosol		Grey Vertosol	Black Vertosol
	Kingaroy (grass)	Kingaroy (legume)	Kupunn	Kingsthorpe
Applied N	100	70	80	160
Fertilizer N in plants	58.1 (±8.2)	59.2 (±6.1)	30.5 (±4.3)	66.7 (±4.3)
Fertilizer N in soil	36.3 (±12.1)	19.1 (±1.1)	17.3 (±5.3)	15.8 (±4.9)
Total (soil+plant)	94.4 (±16.2)	78.3 (±7.2)	48.1 (±7.4)	82.5 (±2.2)
Missing N	5.6 (±16.2)	-8.3 (±7.1)	31.9 (±7.4)	77.5 (±2.2)

Discussion

The observed variation in optimum fertilizer N rate between sites, despite similar starting N in the soil profiles at planting, was consistent with differences in crop yield potential and hence crop N demand. However, the contrast between N dynamics in the experiments on Vertosols and Ferrosol soil types in what was an unusually wet growing season was marked. The variation in AE_{90} values between sites was within the range described by Lester et al. (2008) for short fallow grain sorghum crops and consistently indicated a profitable return from N use. The higher AE_{90} on the Ferrosols was consistent with high fertilizer N recoveries in plant biomass and little fertilizer N loss, while the lower AE_{90} values at the Vertosol sites with similar (Kupunn) or higher (Kingsthorpe) yield potentials were consistent with much poorer recoveries of fertilizer N in crop biomass and evidence of significant proportions of fertilizer N lost to the atmosphere.

The total N_2O emissions recorded at the Kingaroy and Kingsthorpe sites were related to optimum N rate, but in this case were not a good indicator of fertilizer N loss. For example, despite a 3-fold increase in cumulative emissions in the grass v legume history at Kingaroy there was no substantial increase in apparent fertilizer N losses, while a further doubling of emissions at Kingsthorpe resulted in almost 50% of fertilizer N lost. These differences may relate to variation in the N_2O:N_2 ratio during the denitrification events, but the consistency of N losses on both Vertosol sites illustrates the risks to N use efficiency on those soils in summer grain cropping.

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Nitrogen removal and use on a long-term fertilizer experiment

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Abstract
The Dahlen nitrogen and phosphorus experiment was established in 1996 in the medium rainfall cropping zone of Victoria, Australia, and has been in a canola, wheat, barley and pulse rotation each year since then. The experiment has four rates of P (0, 9, 18, 36 P kg/ha) applied at sowing, and five rates of N (0, 20, 40, 80, 160 N kg/ha) either all at sowing or split. Crop and soil data has been collected for each crop year, which included two years where crops were sown but not harvested due to drought. A progressive N balance over the duration of the experiment has shown that N removal-to-fertilizer use ratios for the 9 kg P/ha/y were 2.96 (20 kg N/ha/y), 1.57 (40 kg N/ha/y), 0.92 (80 kg N/ha/y) and 0.47 (160 kg N/ha/y). Fixed N estimates were made based on pulse growth, checked with natural abundance measurements on site which ranged from 40 to 120 kg N/ha/crop depending on season. When fertilizer and legume N inputs are considered, the removal-to-supply ratios were 1.36 (20 kg N/ha/y), 1.04 (40 kg N/ha/y), 0.74 (80 kg N/ha/y) and 0.42 (160 kg N/ha/y). We conclude that this continuous cropping system was maintained as N neutral with the use of one pulse crop in 4 years, and the addition of 40 kg N/ha/y in the non-pulse crops. Soil organic carbon levels were unaffected by N application.

Key words
Nitrogen use efficiency, cropping systems, removal-to-use, fixed nitrogen, rotations.

Introduction
Efficient and effective use of N fertilizers is important in productive and sustainable farming systems (Stewart et al. 2005, Davidson et al. 2015). There are several ways to estimate N efficiency such as agronomic efficiency (AE) or recovery efficiency (RE) (Table 1), which are the marginal increases in yield or N removal to the added fertilizers. The difference indices rely on nil fertilizer checks, and are useful in identifying the relative contribution of soil and fertilizer nutrients, as well as giving a guide to the fate of nutrients not removed in products. They are most often reported from single year experiments, and may be done using tracers to estimate the nutrient recovery efficiency (RE). The use of ^{15}N-labelled fertilizers in field experiments has shown RE in Australian wheat systems of 22-59% in the plant (Freney et al. 1992), whereas Ladha et al. (2005) estimated a mean "global" recovery from isotope studies of 44%.

However, there are few reports of nutrient balances over long-term nutrient management experiments. Analysing the balance of input, removal and changing nutrient stocks over time can identify the true nutrient efficiency of cropping systems as they face the vagaries of climate and the production of different crops in a rotation. This paper reports the nitrogen balance, expressed as Partial Nutrient Balance (BNP) from a long-term (19 years) fertilizer experiment and reports some of the changes in soil properties over that time. This updates an earlier report on the experiment from 1996 to 2010 (Norton et al. 2012).

Methods
The Dahlen long-term nutrition experiment, 10 km west of Horsham Victoria, was established in 1996 to investigate the interaction of different rates of N and P within a minimum tillage and stubble retention cropping system. Since establishment, the site has been in a canola, wheat, barley and pulse rotation although an oaten hay crop was grown in 2011 to help manage herbicide tolerant weeds. The soil at the site is a Vertosol, which is the dominant cropping soil in the region. The mean annual rainfall (1891-2014) for the region (BOM site #079028, Longerenong) is 414 mm, but over the experimental period there were seven years of decile 1 or 2 rainfall, with mean rainfall over the duration of the experiment of 375 mm. The fertilizer treatments imposed are five rates of nitrogen (0, 20, 40, 80, 160 kg N as urea) and four rates of phosphorus (0, 9, 18, 36 kg P as triple super) applied annually over the past 19 years. No N is applied during the pulse phase of the rotation and but full applications of N and P occurred in drought years when no crop was harvested (2002, 2006). Prior to 2011, there were two series of N treatments; either all N at sowing or split 50:50 between sowing and stem elongation, and the results reported here are for where N was applied at only at sowing.

Table 1. Dimensions of nutrient use efficiency (after Dobermann 2007).

Metric	Calculation	Range for N in cereal crops
Apparent Recovery Efficiency	RE = kg increase in uptake kg^{-1} applied = $(U - U_0)/F$ (whole plant) = $(Ug-U_0g)/F$ (grain only)	0.3 to 0.5 kg/kg; 0.5 to 0.8 in well managed systems, at low N use level or at low soil N supply.
Agronomic Efficiency	AE = kg yield increase kg^{-1} nutrient applied = $(Y-Y_0)/F$	10 to 30 kg/kg; >25 in well managed systems, at low N use or at low soil N supply
Partial Nutrient Balance (Nutrient Removal Ratio)	PNB = kg nutrient removed kg^{-1} applied = Ug/F	0.1 to 0.9 kg/kg; >0.5 where background supply is high and/or where nutrient losses are low.
Partial Factor Productivity	PFP = kg yield kg^{-1} nutrient applied = $Y/F = (Y_0/F)$	40-80 kg/kg: >60 in well managed systems, at low N use or at low soil N supply

Y=crop yield with applied nutrients; Y_0=crop yield with no applied nutrients; F=nutirents applied; U=plant nutrient content of above ground biomass at maturity with applied nutrients; U_0=plant nutrient content uptake with no applied nutrients; Ug=grain nutrient content with applied nutrients; U_0g=grain nutrient content with no applied nutrients.

Product samples were taken at harvest and yields are adjusted to 10% (cereals and pulses), 8% (canola) or 0% (hay) moisture contents. Product N content was assessed using NIR in each year. N removal (product of nutrient content and yield) and fertilizer input were used to construct nutrient balances for the period 1996 to 2014. The amount of N fixed during the legume phases (Ndfa) was estimated as the product of three times the grain yield (peak biomass) and 25 kg N/ha/t (Peoples et al. 2001). These estimates were validated against Ndfa measured using the natural abundance method on the lentil crop (2005).

After the 2014 canola crop, the whole site (120 plots) was sampled in the top 10 cm for Colwell P, mineral N, total soil N, C and P. In addition, all plots were sampled for mineral N to 90 cm. Soil tests were also available from prior to the first crop in 1996. These data were analysed using a factorial analysis of variance with four rates of P and 5 rates of N combined, although only selected combinations are presented here.

Results and discussion

The annual yields for the period 1996-2014 are summarized in Table 2. All the subsequent nutrient balances analyses include the two failed years (2002, 2006) where fertilizer was applied but no crop removed. Crop growing conditions were good for the first few years of the experiment, but low rainfall over the "Millennium Drought" saw low yields in comparison to long term values. In all but one year, N (lentils, 2005) and P (barley, 2008) treatments resulted in significant yield responses. There were interactions between N and P in nine of the 19 years, and the nature of this interaction was that there was no response to N when P was not applied.

Table 3 gives the soil test values for selected treatments following the 2014 canola crop. Mineral N concentration to 90 cm was significantly higher under the 160 kg N/ha/y treatment with an additional 230 kg N/ha accumulated compared to the lower rates. Previous samplings (Norton et al. 2012) showed there could be as much as an additional 300 kg N deeper than 90 cm under the highest application rate. In contrast, the moderate N rates showed similar mineral N concentrations to 90 cm, although there was a trend for the 80 kg N/ha/y rate to have more deep N than the lower rates. The occurrence of nitrate leaching is corroborated by the decline in soil pH (top 10 cm) by almost 0.5 pH units. So, very high rates of applied N can result in leached N, even though the soil is fine textured, and in general, the seasons have been relatively dry. The more common N rates in this region are 25 kg N/ha/y on cereals and 45 kg N/ha/y on canola, so that at those application rates the potential for leaching losses is low.

Soil organic C concentrations at the commencement of the experiment were 1.14±0.18% and this is similar to the organic C values for the N treatments. Soil organic C was significantly increased with higher P rates (data not shown) but N application caused no significant change in organic C. This contrast the report by Khan et al. (2007) from the long-term "Morrow" plots in the United States of America. Gove et al. (2009) suggest that the results from the Morrow plots are confounded by the use of inappropriate controls.

Table 2. Mean site yields (t/ha) across all treatments and the level of significance of the yield response to N, P and the interaction of N and P. ns not significant (p>0.05); * p<0.05; ** p<0.01; *** p<0.001.

Year	Annual Rainfall (mm)	Crop	Site Mean (t/ha)	N response	P response	N*P response
1996	458	Barley	3.26	***	***	***
1997	311	Chickpea	1.62	***	***	ns
1998	393	Canola	1.58	***	***	***
1999	401	Wheat	1.88	***	***	ns
2000	347	Barley	3.08	***	***	***
2001	396	Lentils	0.90	***	***	***
2002	245	Canola		Crop failure, drought		
2003	463	Wheat	3.68	***	***	***
2004	303	Barley	1.00	***	***	***
2005	391	Lentil	1.03	ns	***	ns
2006	235	Canola		Crop failure, drought		
2007	417	Wheat	2.18	**	**	ns
2008	328	Barley	1.10	***	ns	***
2009	455	Chickpea	0.48	***	***	ns
2010	496	Canola	2.45	***	***	ns
2011	536	Oaten Hay	6.42	ns	***	ns
2012	290	Wheat	4.75	***	***	ns
2013	400	Barley	4.34	***	***	***
2014	256	Canola	0.82	***	***	ns

Table 3. Mean yield (1996-2014), soil mineral N, organic carbon (OC) and soil pH levels after the 2014 crop. N balance (fertilizer+Ndfa) and partial nutrient balances (PNB) are also given. Values are for the 9 kg P/ha phosphorus treatment. LSD values are for the interaction N*P where significant (Yield, Min N), otherwise it is for the N responses alone (OC%, pH).

N Rate (kg/ha/y)	Yield (t/ha)	OC (0-10 cm) (%)	Min N (0-90) kg N/ha	pH (0-10 cm) ($CaCl_2$)	N balance (kg N/ha)	PNB (fert. alone)	PNB (fert.+ Ndfa)
0	1.90	0.99	33	7.22	-307	-	1.87
20	2.29	1.05	31	7.27	-224	2.96	1.36
40	2.22	1.05	54	7.28	-42	1.57	1.04
80	2.31	1.04	74	7.32	355	0.92	0.74
160	2.32	1.02	303	6.83	1454	0.47	0.42
LSD (p<0.05)	0.09	ns	89	0.25	-	-	-

Table 3 also contains estimates of N balances (removal less fertilizer and Ndfa inputs) and PNB over the duration of the experiment. Two estimates are used in estimating the PNB, one with the fertilizer inputs alone, and the other with the sum of fixed and applied N. The amount of Ndfa varied from year to year (mean values of 122 kg N/ha (1997), 67 kg N/ha (2001), 75 kg N/ha (2005) and 36 kg N/ha (2009)) in response to mean yields, and also in response to P application. The Ndfa rose from a mean of 59 kg N/ha/year to 82 kg N/ha/y where P was applied compared to nil P. The inclusion of Ndfa provides a more realistic assessment of the N balance of the system, rather than just considering a single year crop.

For this rotation that includes one crop in four as a pulse, the N balance including fertilizer and Ndfa for the nil N application was -307 kg N/ha and as N was added, the system removal and use approached a balance at 40 kg N/ha/y. If less than 40 kg N/ha/y was applied, N was being depleted from the system, although the topsoil mineral and the soil organic C (organic matter) do not necessarily reflect that decline. Data from 2010 a similar result was seen where N rate did not affect organic C, but there were significant declines where no P was used (Norton et al. 2012).

Table 4 shows the different metrics derived for this rotation over time. The first point to note is that all efficiency metrics are highest at the lowest N rate, as would be expected given the nature of a fertilizer

response curve characterised by diminishing returns. Recovery efficiency in grain and PNB both give an assessment of the balance of nutrients, and the values at 40 kg N/ha/y for RE in grain indicate that half the applied N is not recovered but the PNB suggests that all the N, plus the contribution from Ndfa is recovered. The same data are used, and so this emphasises the importance of qualifying the metrics used when discussing nutrient use efficiency, especially as difference indices do give quite a different assessment of the situation. A similar comparison applies to the AE and PNB comparisons in Table 4.

Table 4. Nitrogen fertilizer use efficiency metrics from the Dahlen long-term fertilizer experiment. All values are for the 9 kg P/ha rate and the metrics used are explained in Table 1.

N Rate (kg N/ha/y)	AE	RE	PFP	PNB
20	22.4	0.54	141	1.36
40	11.4	0.47	71	1.04
80	7.9	0.37	38	0.74
160	3.1	0.19	18	0.42

During the first few years of the experiment, the progressive N balance for the 20 kg N/ha/y and 40 kg N/ha/y were close to balanced, but with the onset of the Millennium drought and relatively poor years, the 40 kg N/ha/y rate built up a surplus of around 150 kg N/ha, which was then drawn down in the better years from 2009 and was -42 kg N/ha by the end of 2014. Therefore at moderate N rates, in this environment unused N is essentially preserved from one season to the next, or even over several seasons. In these soils, providing application rates are moderate, leaching losses are small, and the dry soils mean denitrification is likely to be low. A long-term N strategy with rates that reflect the annual removals and include Ndfa is a reasonable starting point for a fertilizer strategy for these soils.

Conclusion

This example represents a modern continuous cropping system using both fixed N and fertilizer N. Overall, N losses appear to be low when rates are less than 80 kg N/ha/y, and at 40 kg N/ha/y the system with one crop in four as a pulse seems in approximate N balance.

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Nitrogen use efficiency for pasture production – impact of enhanced efficiency fertilisers and N rate

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Abstract
Nitrogen (N) use efficiency from granular urea application to pastures is often low (<50%) and could be improved by using enhanced efficiency fertilisers (EEFs). EEFs include nitrification inhibitors, urease inhibitors and controlled release fertilisers. A field trial established at Wye in South Australia (May-2014 to February 2015) compared biomass production in a rainfed perennial ryegrass pasture with urea and EEFs applied 5 times (May 6th, May 27th, July 3rd, August 21st and October 3rd 2014) at three N rates (17, 34 and 50 kg N ha-1). The EEFs applied were urea + urease inhibitor (n-(N-butyl) phosphoric triamide (NBPT) applied as Green UreaNV® (GU)), urea + nitrification inhibitor (3,4-dimethylpyrazole phosphate (DMPP) applied as Urea with ENTEC® (EU)) and polymer coated urea (2 month release) (PCU), and these were compared to urea (U). Cumulative biomass across all treatments ranged from 2.8 to 4.5 t dry matter (DM) ha-1. Biomass production increased with N input, but was reduced by the use of PCU. Cumulative apparent nitrogen use efficiency (NUE) (kg net-N uptake per unit N applied) ranged from 16 to 53%, and was generally greater with lower N input rates. NUE varied for each harvest, reflecting seasonal differences in biomass production, and between treatments. GU had the highest NUE at the lowest rate of N (17 kg N ha-1 per fertilisation event) suggesting substantial reductions in N loss. At higher N rates, N in excess of plant requirements may have prevented a response. The lower NUE of the PCU reflects the initial limited availability of N due to the slow release nature of the polymer coated fertiliser. The results show that efficient management of N in pasture systems requires matching N inputs to pasture requirements and this requires an understanding of the seasonal biomass responses and N losses that can occur.

Key words
Fertiliser nitrogen, surface broadcast, nitrogen loss

Introduction
Enhanced efficiency fertilisers (EEFs) are designed to reduce specific nitrogen (N) loss pathways. For example, the urease inhibitors slow urea hydrolysis and target ammonia (NH_3) volatilisation; the nitrification inhibitors slow nitrification and so target losses from nitrate (NO_3^-) leaching and gaseous emissions of nitrous oxide (N_2O) and dinitrogen (N_2) from nitrification and subsequent denitrification; the coated N fertilisers slow the release of N and so theoretically supply N at a rate that matches plant demand, reducing the risks of loss from all pathways. The EEFs have been reported to be effective in targeting different loss pathways from N applied to pastures (Suter et al. 2013; Singh et al. 2004), however the impact of the 'saved' N on biomass productivity is variable (Zaman et al. 2009; Dawar et al. 2011). The reasons for this remain unclear. Sometimes benefits may not be seen because experiments are established using standard grower application rates with and without addition of EEFs, so that sufficient N is being supplied even when losses occur. At other times the benefits may not be seen because climatic conditions are such that little N is lost through the targeted pathway. Therefore in order to assess the productivity benefit from the 'saved' N, experimental field trials need to apply N; 1) over a range of rates to incorporate those where N is applied below that required for optimal growth, and 2) across seasons to include the times when losses through the different pathways will be high. A small plot field experiment was established at Wye, SA (38°01'16" S, 140°53'12" E) on a rainfed ryegrass dominated pasture to assess the impact of different EEFs on biomass production, with N applied at three different rates (grower practice and 2 sub-optimal rates) over a nine month period (May 2014 to February 2015).

Materials and Methods
Background soil properties were measured across the plots prior to commencement of the experiment (12th April 2014). The soil at the site was a Tenosol; the surface horizon (0-10 cm) was a loamy sand with 3.7%

clay, 16.9% silt and 80.4% sand, and had an initial pH_{CaCl2} of 4.9. Soil total N and carbon (C) were 0.5% and 5.4% respectively. The bulk density of the soil was 1.0 g cm^{-3} (0-5 cm) and 1.1 g cm^{-3} (5-10 cm). The cation exchange capacity was 9.7 cmol (+) kg $soil^{-1}$. At commencement of the experiment the 0-10 cm soil layer contained 6.9 mg N kg^{-1} as ammonium (NH_4^+), 20 mg N kg^{-1} as nitrate (NO_3^-), 30 mg kg^{-1} Colwell P, 122 mg kg^{-1} available K, 0.5 mg kg^{-1} Zn (DTPA) and 12 mg kg^{-1} sulfate S (MCP). The pasture was dominated by perennial ryegrass with lesser amounts of cocksfoot, barley grass, subclover, and some annual grass species.

The small plot (5 m x 5 m) experiment was a completely randomised design with treatments replicated 4 times. The treatments were;

i) Control (no fertiliser, C),
ii-iv) Granular urea (U) at 3 rates (17, 34 and 50 kg N ha-1),
v-vii) Granular urea plus the nitrification inhibitor 3,4-dimethyl pyrazole phosphate (EU, applied as Urea with ENTEC®) at 3 rates (17, 34 and 50 kg N ha-1),
viii-x) Granular urea plus the urease inhibitor n-(N-butyl) phosphoric triamide (GU, applied as Green UreaNV®) at 3 rates (17, 34 and 50 kg N ha-1), and
xi-xiii) Polymer coated granular urea with a 2 month release pattern (PCU, applied as a 2 month release product at 3 rates (17, 34 and 50 kg N ha-1).

Each treatment was surface applied on May 6th, May 27th, July 3rd, August 21st and October 3rd 2014. No fertiliser was applied after October 3rd, as per standard local practice, as little pasture growth was expected due to high temperatures and low rainfall. The repeated N applications were made to the same plots to simulate standard pasture management practice of fertilisation following grazing. Total N application over the experiment was 85, 170 and 250 kg N ha^{-1} for the 17, 34 and 50 kg N ha^{-1} rates respectively. Basal nutrients were applied once on May 6th at a rate of 30 kg P ha^{-1}, 50 kg K ha^{-1} and 3.5 kg Zn ha^{-1}.

Biomass cuts (2.3 m^2) were taken from within each plot on May 26th (20 days after fertiliser (DAF)), July 3rd (37 DAF), August 21st (49 DAF), October 1st (41 DAF), October 23rd (20 DAF) in 2014, and February 9th 2015 (129 DAF). Collected biomass was dried at 60°C to constant weight for dry matter (DM) production (kg DM ha^{-1}). Subsamples were ground to a powder (~ 100 mm, Tissue lyser) and analysed for total C and N using a combustion technique (Hydra 20-20, SerCon).

Total rainfall (Figure 1) for the experimental period was 538 mm. For each pasture growth period the rainfall was 30 (May 6-26th), 197 (May 27th-July 3rd), 140 (July 3rd-August 21st), 44 (August 21st-October 3rd), 22 (October 3rd-October 23rd) and 106 (October 23rd-February 9th) mm.

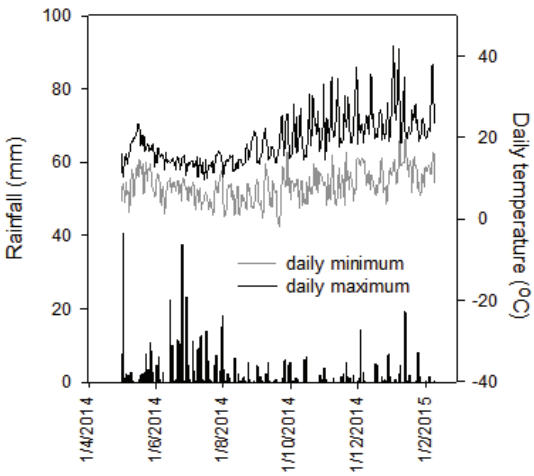

Figure 1: Rainfall and air temperature (minimum and maximum)

Results

Application of N increased cumulative biomass production by 40 to 220% compared to the control (2.0 ± 0.4 t DM ha^{-1}) (Table 1). The biomass response followed the growing seasons with significantly ($P<0.05$) more biomass (>1 t dry DM ha^{-1}) in the 21st August and 1st October harvests than in the other months (190-550 kg DM ha^{-1}). In addition there was significantly ($P<0.05$) more biomass in the July harvest (550 kg DM ha^{-1})

than in the 26th May, 23rd October, 9th February harvests (190-350 kg DM ha^{-1}). This is illustrated for the 34 kg N ha^{-1} application per fertilisation date in Figure 2. However there was no significant difference in the mean biomass production for the fertiliser treatments either cumulative (Table 1) or for each sample date (Figure 2).

Table 1. Average cumulative biomass and apparent nitrogen use efficiency (NUE) for the different treatments and N application rates, from May 2014 to February 2015 (± standard deviation).

N applied (kg N ha^{-1})$^{+}$	Biomass (t DM ha^{-1})			Apparent nitrogen use efficiency (NUE)* (%)		
	85	170	250	85	170	250
Treatment						
U	3.1 ± 1.1	4.1 ± 1.2	4.5 ± 0.9	47 ±32	40 ±21	33 ± 13
EU	3.0 ± 0.4	4.0 ± 0.9	4.2 ± 1.1	35 ± 16	37 ± 15	32 ± 17
GU	3.3 ± 0.6	3.8 ± 1.1	4.3 ± 1.2	53 ± 19	40 ± 173	34 ± 14
PCU	2.8 ± 0.8	3.0 ± 0.4	3.3 ± 0.4	36 ±29	21 ± 7	16 ± 15

*Apparent NUE = (N uptake in the treatment (kg N ha^{-1}) – N uptake in the control (kg N ha^{-1}))/(N applied (kg N ha^{-1})) x 100. N uptake = pasture DM (above ground biomass) (kg ha^{-1}) x N content (%) of the above ground biomass
$^{+}$ N applied is the cumulative rate for 5 applications of 17, 34 and 50 kg N ha^{-1}.

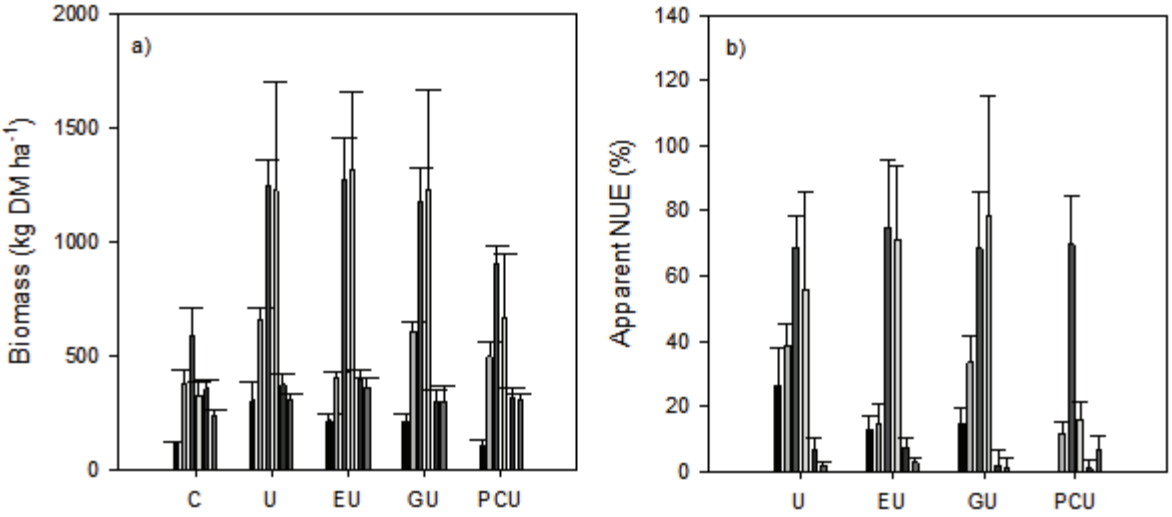

Figure 2: Biomass (a) and apparent NUE (b) for the different treatments at each sample date (May 26th (□), July 7th (□), August 21st (□), October 1st (□), and October 23rd (□) 2014, and February 9th (□) 2015) with application of 34 kg N ha^{-1} per fertilization date. Error bars are standard errors of the mean of 4 replicates.

The cumulative DM response averaged 10 kg DM per kg N applied (range 5-15) across all treatments. Across the individual harvests the DM response ranged from nil to 36 kg DM kg N^{-1}. There was a significantly ($P<0.05$) greater DM response to N in the 21st August and 1st October harvests (average 17 and 22 kg DM per kg N applied respectively). The average DM response to N in the 3rd July harvest (5 kg DM per kg N applied) was significantly ($P<0.05$) greater than that in the 26th May, 23rd October, 9th February harvests (-0.5-3 kg DM per kg N applied) (Figure 2).

There was no significant difference in the apparent NUE based on either the cumulative or individual pasture harvests across all treatments. The cumulative apparent NUE ranged from 16 to 53 % (Table 1). Apparent NUE across all treatments and all harvest dates ranged from -4 to 119% (data not shown), with greater efficiency at lower N application rates. There was significantly ($P<0.05$) higher NUE in the 21st August and 1st October harvests (average 69 and 61%, respectively). The highest NUE on both dates was for the GU17 treatment (91 and 119% on 1st October and 21st August respectively). The average NUE in the 3rd July harvest (26%) was significantly ($P<0.05$) greater than that in the 26th May, 23rd October, 9th February harvests (4-10%). The variation in apparent NUE with time of harvest is depicted in Figure 2 for the 34 kg N ha^{-1} application per fertilisation event rate.

Discussion

Temperature and rainfall fluctuated over the course of the experiment reflecting the different seasons, which led to variations in pasture biomass production (Figures 1 and 2).

The highest production period was between July and October when there was sufficient soil moisture for growth. The lowest production occurred in May, and late October to February which reflected hotter drier conditions, with only 129 mm of rain falling between October 1st 2014 and February 9th 2015. The site showed a responsiveness to N with increased N inputs leading to increased biomass production. However the increase in N inputs led to decreased NUE, suggesting a non-linearity in the N response curve across the N rates used. When conditions were optimal for growth (July to October) the NUE was highest as pasture growth was not limited by other factors. At other times the NUE was lower as other factors, such as limited water, affected the conversion of N into biomass. Overall the PCU had comparatively low NUE (particularly in May when the NUE was 0% due to the slow release and hence uptake of N), resulting from the slow release nature of the product (2 month release pattern). The release of N from the PCU product appears to be too slow for plant demand, particularly during periods of high growth.

The main reason for no observable major effect of the EEF treatments on biomass production and NUE over the course of the experiment, with the exception of the GU at lower rate, could be due to a combination of 1) other factors influencing biomass production (mainly water), particularly outside the July-October period, 2) low ammonia loss at other times, due to cooler wet conditions, so whilst N may be saved in the urease inhibitor (GU) fertiliser treatments this additional N only has a positive impact when N application is low (17 kg N ha^{-1}), 3) low loss from targeted pathways (eg. leaching and denitrification losses targeted by the nitrification inhibitors (EU)), and 4) high growth rates (optimal conditions) so that any small savings in N with the EEFs do not translate into biomass because the system is operating at a higher efficiency (NUE). Powell et al. (2010) report NUE from fertiliser in dairy pastures ranging from 17 to 77%, suggesting that the system we examined is operating at the upper end of NUE during periods of high productivity. The short term impacts of reducing N loss with the EEFs on biomass productivity may not been seen due to availability of sufficient N from the soil reserves (Total N 0.5%, 20 mg kg^{-1} NO_3^- at commencement of the trial).

Conclusion

Increasing N inputs to the rainfed ryegrass pasture led to greater biomass production, but reduced the NUE of the fertilisers. The role of EEFs was unclear, with improvements in productivity and NUE seen only for the GU on a single harvest date, and the PCU showed decreased productivity. Improving the efficiency of N management in pastures requires an understanding of the seasonally determined potential productivity and the drivers of low or high efficiency. Through this understanding, application of N to better match plant needs, whether through use of EEFs or by adjusting one or a combination of N rate, timing and choice of product, can be used to improve the efficiency of conversion of fertiliser N to pasture biomass.

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Development of nitrogen dilution curves for current Australian wheat varieties

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Abstract
Accurate nitrogen (N) application rates are of major importance in agriculture. While fertiliser guidelines have improved, the relationship between yield and N rates remain the main reference. However, this relationship is highly variable with soil, variety and season. A better reference is a 'nitrogen dilution curve' which relates the critical N concentration of wheat shoots (i.e. the lowest concentration of N needed to achieve maximum growth and (theoretically) maximum yield), with biomass. Crops can be benchmarked against this curve to determine their N status, i.e. assess if N fertiliser is applied at the correct rate, or if the crop is over- or under-fertilised. Nitrogen dilution curves exist for winter wheat, but these are developed for irrigated (non-drought stressed) crops and for older (European and Asian) wheat varieties. In South Australia, winter wheat is grown under rain-fed conditions where water and N may co-limit biomass production. In addition, breeding for grain yield has shifted the biomass-nitrogen balance over the past 20 years and the original dilution curve needs to be updated. Here we introduce the GRDC funded project "Benchmarking wheat yield against nitrogen use" (2014-2017). During this project N dilution curves will be produced for current wheat varieties under irrigated and rain-fed conditions. We will assess how drought stress may change the parameters of the curves and how this affects yield. The curves can be used to benchmark wheat in both growers' fields and National Variety Trials. Here we present preliminary results from the first year (2014) of the project and outline the trials for the next two years.

Key words
N status, Nitrogen Nutrition Index, SPAD, Greenseeker, ^{13}C analysis, diagnostic tools.

Introduction

Accurate nitrogen (N) application rates are of major importance in agriculture. Over-application of N can lead to less productive crops and environmental pollution. Continued under-fertilisation leads to soil N mining and yield gaps. In South Australia, farmers are often conservative in their use of N fertiliser because of uncertain rainfall and associated (financial) risks. Consequently, is not uncommon that in seasons with average or above average rainfall, wheat crops in South Australia experience some degree of N deficiency (Sadras 2002).

Despite the importance of N for crop yield and its incidence in the variable costs of farm businesses, there is no established benchmark to assess the N status of crops. Fertiliser guidelines have improved over recent years, with emerging technologies based on canopy size and greenness. However, yield-N relationships remain the main reference. A major limitation of this approach is that yield-N relations are highly variable with soil, crop and season (Sadras and Lemaire 2014).

There is a strong relationship between crop biomass and crop N content. As the crop matures there is a reduction in the levels of N concentration requirements to achieve maximum plant growth (Greenwood et al. 1990). This happens for several reasons. Young crops are mostly leaves, with high N concentration for photosynthetic processes. After stem elongation, the leaf:stem proportion declines, and the lower N concentration in stems drives the whole-shoot N concentration down (Lemaire *et al*. 2008). In addition, as the crop grows, N is relocated from shaded leaves in lower position of the canopy to well-illuminated leaves at the top of the canopy (Hikosaka 2005). The concentration of N in a plant is thus related to its actual biomass. If, due to for example, sowing date or wheat variety, wheat biomass in one trial is lower than in another trial, N concentrations cannot be effectively compared because each crop requires a different amount of N to achieve maximum growth. In order to assess the N status of a crop, we must account for crop biomass.

Nitrogen Dilution Curve and Nitrogen Nutrition Index
To account for crop biomass when determining the N status of a crop, a 'nitrogen dilution curve' and 'nitrogen nutrition index' (NNI) should be used (Lemaire and Meynard 1997). A nitrogen dilution curve shows the minimal concentration of N in shoots that is required to achieve maximum growth, i.e. the *critical N concentration*, plotted against biomass. Wheat crops can be benchmarked against this curve by deriving the NNI. The NNI is calculated by dividing the actual N concentration of the crop at a given biomass, by the critical N concentration derived from the N dilution curve at that same biomass. If the NNI is 1, then the actual N concentration is at the critical level and growth is maximum. When the NNI is < 1, this indicates that the crop may be N deficient while higher than 1 means the increase in N uptake does not increase crop growth and is "luxury" consumption of N.

Nitrogen dilution curves have been developed for irrigated winter wheat by e.g. Justes *et al*. (1994) in France and Zhao *et al*. (2014) in China. In South Australia however, winter wheat is grown under rain-fed conditions where water and N may co-limit biomass production (Sadras 2005). Further, new wheat varieties in Australia have an increased capacity to uptake N from the soil (Sadras and Lawson 2012). New wheat varieties may therefore have different critical N and higher fertiliser requirements. In this GRDC funded project, we will produce a new nitrogen dilution curve for current Australian wheat varieties in rain-fed systems under Mediterranean climate conditions. We will also assess how drought stress affects the parameters for the N dilution curve. The new nitrogen dilution curve can help improve diagnostic criteria and management of N fertiliser application in both growers' fields and National Variety Trials (NVT).

Here we present a subset of the results from the first year of the project. We also outline the rest of the project in the "Trials 2015-2016" section.

Methods
In 2014, a full factorial trial was established with four current wheat varieties (Mace, RAC1843, Scout and Trojan) and five N fertiliser rates (0, 60, and split applications totalling 120, 180, 240 kg-N/ha) at two locations in South Australia, Hart (33°45'10 S, 138°23'51 E, red dermosol) and Turretfield (34°32'32 S, 138°47'20 E, red brown earth). Total rainfall in the April-October season was about average for both Hart and Turretfield (±350 and 270 mm respectively), however both sites had relatively dry endings of the season. Turretfield was sown about 2 weeks later than Hart.

Aboveground biomass was sampled fortnightly starting at tillering to determine biomass and N content. At maturity, biomass was harvested for yield and yield components. A preliminary dilution curve for the 2014 data was fitted following the general procedure of Justes *et al*. (1994) with some modifications: in short, for each location and sampling date, N treatments were compared to determine the point where an increase in N concentration of the biomass did not significantly increase biomass dry weight. The N concentration after which no significant increase in biomass dry weight occurred is the critical N concentration. Statistical analysis was done using one-way ANOVA and Duncans post hoc testing. Not all sampling dates could be used to calculated critical N concentrations due to a lack of significant difference in biomass among the treatments. From the 2014 data, five sampling dates (i,e. 4 data points from Hart and 1 from Turretfield) could be used to construct the preliminary curve (Fig. 1). As this is a limited number, the preliminary dilution curve and related Nitrogen Nutrition Indexes should be interpreted with this in mind.

Results and discussion
A preliminary nitrogen dilution curve was fitted in Figure 1.

Using data from the trials to explore yield responses to NNI, we expected an initial increase in yield with an increase in NNI, yields peaking when the NNI is around 1, and decreasing yields when NNI is larger than 1. At Hart, yield more or less followed the expected trend in relation to NNI (Fig. 2b). Though more obviously for NNI values >1 than <1. At Turretfield yield was highest for NNI's <1, and decreased with an increase in NNI (Fig. 2a). As Turretfield was sown and harvested later than Hart, crops at this location may have been more affected by drought stress at the end of the season, causing the crops with a lower N status to produce higher yields. Because the preliminary curve was constructed mostly with data points from Hart, the

preliminary curve may be better representing crops that are less affected by drought stress. This hypothesis will be tested in the next two seasons of the project (see "Trials 2015-2016" section below).

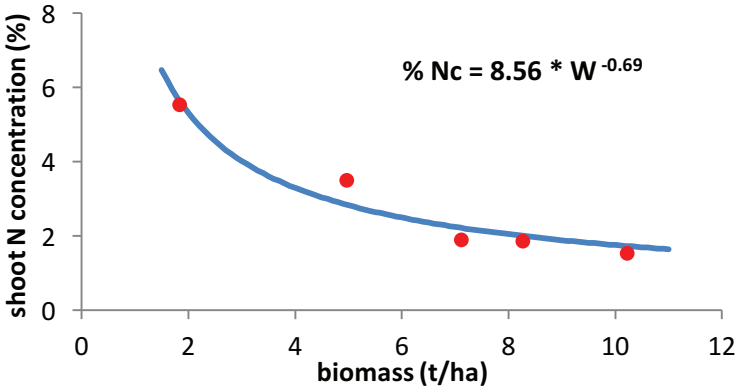

Figure 1. Preliminary nitrogen dilution curve. Red dots are critical N concentrations calculated from the 2014 data and used to fit the dilution curve. The concentration of N in shoots required to achieve maximum growth declines with increasing biomass. Nc: critical nitrogen concentration (%), W: biomass (t/ha).

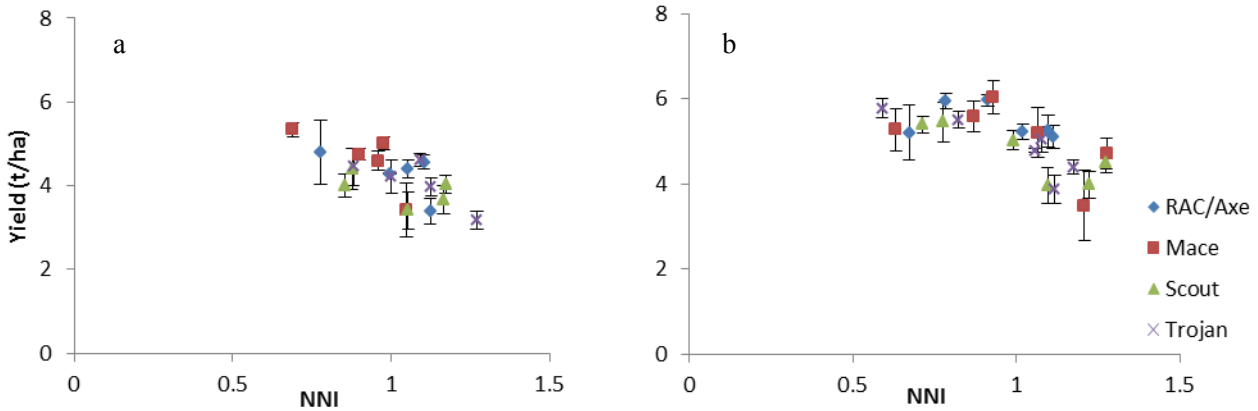

Figure 2. Yield vs. nitrogen nutrition index (NNI) per wheat variety at flowering. (a) Turretfield (blue diamond refers to RAC1843), and (b) Hart (blue diamond refers to Axe). Data points represent the average NNI in each N rate treatment (N = 3).

A reduction in yield under high N rates (NNI > 1) is often reported when high vegetative growth constrains grain fill because soil moisture gets depleted sooner. Interestingly, we did not find a significant increase in total biomass with an increase in N rate (data not shown) but we did find an increase in the leaf:stem ratio. A relatively higher amount of leaf biomass in the high N treatments may still indicate higher transpiration rates and a quicker depletion of soil moisture. Furthermore we found that the reduction in yield was mostly related to 1000-grain weight (as opposed to e.g. grain number), which has previously been found to be caused by high levels of N (Ferrante et al. 2010).

Trials 2015-2016

In the 2015 and 2016 growing seasons, similar full factorial trials will be set up under both rain fed and irrigated conditions. We will use ^{13}C isotope analysis and canopy temperature measurements to assess the degree of drought stress in the rain fed trials compared with the irrigated trials and compare how the N dilution curve parameters change for drought stressed crops.

In order to make the NNI a more practical tool for farmers, we also test two methods to measure proxies for shoot N in the field. We use a SPAD meter that measures chlorophyll content and a handheld Greenseeker to measure crop greenness (normalised difference vegetation index, NDVI).

During all seasons, samples are also collected from commercial farmers' fields and National Variety Trials (NVT) to get an indication of the current N status in crops and NVT in the mid north region in South Australia.

Conclusions

While a preliminary dilution curve was constructed using 2014 data, additional data is needed from the 2015 and 2016 seasons to produce a more robust dilution curve. Using data from the trials planned in 2015 and 2016 for rain fed and irrigated crops, we will assess how drought stress affects the parameters of the dilution curve and use this to make predictions for crop N requirements in years with below average rainfall.

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The effect of agronomic management on gross margins from crop sequences in the high rainfall zone of south western Victoria

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Abstract
Alternating cereal crops with canola and pulses has been shown to mitigate disease and weed pressures, with pulse crops potentially providing an additional source of nitrogen (N). However, there is a lack of information regarding the financial effect of agronomic management on crop sequence profitability. Two separate crop competitions were conducted at Inverleigh and Lake Bolac in the high rainfall zone of south western Victoria from 2011 to 2013. At each site plots were established for competing teams to grow and manage their respective sequence of pulse, canola and wheat crops. Teams consisted of either, farmers, advisers, researchers or academics, competing to achieve the highest yearly and three year rotational gross margin. The choice of pulse and crop variety, sowing, in-crop management and grain marketing were at the discretion of each team. Both crop competitions showed large variations in returns, despite all teams growing identical sequences of crops on the same soil types and receiving the same amounts of rainfall. Teams that produced high yielding crops whilst minimising their costs of production achieved higher margins, with the winning teams generating an extra $1379/ha and $1724/ha over the course of the competition compared with the worst performing teams at the Inverleigh and Lake Bolac sites, respectively. Effective weed control; conservative N fertiliser application to canola and wheat; timely fungicide applications to the pulse and wheat crops; and the selection of long seasoned wheat varieties that capitalised on favourable late growing season conditions in 2013 were influential strategies for increasing gross margins.

Key words
Pulse, canola, wheat, break crop, crop sequence, gross margin.

Introduction

Yields from continuous cereal cropping often decline from a build-up of soil or stubble borne diseases, or diminishing soil N supply (Kirkegaard et al. 2008). Rotating cereals with canola and pulses (break crops) can disrupt disease cycles, with pulse crops providing N fixed from the atmosphere (Peoples et al. 2001), and potentially supplying a cheaper source of N to following crops. N derived from pulse crops have the potential to reduce the cost of production, with N fertiliser representing a significant variable cost for most commercial grain growers (McClelland and Norton 2014). Furthermore, different herbicides are used to control weeds in break crops compared with cereals, and less frequent use of herbicides with the same mode of action can slow the development of herbicide resistant weed populations.

While the benefits of including break crops in crop sequences are well documented, there is often a lack of information regarding the financial implications of agronomic management on the viability of crop sequences that include pulse crops. Gross margins help evaluate the financial effect of agronomic decision making across similar enterprises, however, they do not account for all fixed and overhead costs (eg depreciation, interest payments, rates, or permanent labour) and are a guide to profitability (PIRSA 2014). In this paper we compare yield, variable and some fixed costs and net income from teams competing to achieve the highest gross margin from two separate crop competitions conducted in south western Victoria. Thus identifying the key agronomic management strategies, that can enhance financial returns from crop sequences in the high rainfall zone.

Methods

Two crop competition sites were established at Inverleigh (143°9'E, 38°09'S) and Lake Bolac (142°8'E, 37°72'S) in south west Victoria, commencing in 2011 and finishing in 2013. At each site, eight 2 x 12 m

plots were allocated to each competing team to grow and manage their respective sequences of crops over the three year period. Each team consisted of either farmers, advisers, researchers or academics, competing against one another to achieve the highest yearly and three year rotational gross margin. The choice of pulse and crop variety, sowing and in-crop management and grain marketing were at the discretion of each team. However, a pulse had to be grown in 2011, and all teams chose to grow canola in 2012, followed by a compulsory wheat crop in 2013. Any team that did not compete for the full three years of the sequence or had failed wheat crops in 2013 have not been included in the results.

Nominated captains from each team directed management for each crop in the sequence through the Southern Farming Systems Trial Coordinator, who was then responsible for implementing the management on behalf of each team. The Trial Coordinator recorded the date, rate and cost for every management input imposed by each team. Grain yield for each crop was measured by mechanically harvesting each plot, and a grain sub-sample retained for quality assessment. Gross margins were calculated by multiplying grain yield by price determined by grain quality and corresponding grain segregation, less variable and some fixed costs (Table 1).

Table 1. Variable and some fixed costs ($/ha) for each team at Inverleigh and Lake Bolac, from 2011 to 2013, in south west Victoria.

	Inverleigh							Lake Bolac						
Team	A	B	C	D	E	F		G	H	I	J	K	L	M
							2011							
Seed[1]	174	269	228	106	151	167		244	108	282	295	68	103	155
Fertiliser[2]	100	0	67	59	65	54		65	136	64	104	67	50	58
Herbicide[3]	57	27	108	41	39	36		45	19	35	36	28	28	23
Insecticide	0	0	0	3	0	4		2	0	0	0	0	0	32
Fungicide	20	0	11	0	0	0		42	0	50	26	0	0	0
Fixed[4]	175	80	155	165	160	165		175	105	175	165	155	145	103
Total	526	376	569	374	415	426		573	368	606	626	318	326	371
							2012							
Seed[1]	64	59	71	71	71	71		71	51	51	71	39	34	94
Fertiliser[2]	181	125	132	197	165	161		136	279	146	183	128	778	239
Herbicide[3]	50	44	64	60	22	40		28	69	47	48	36	28	19
Insecticide	0	1	2	32	25	31		41	41	41	41	41	82	41
Fungicide	8	16	8	8	10	7		0	0	8	8	8	0	32
Fixed[4]	169	207	179	191	181	171		167	189	167	189	167	601	209
Total	472	452	456	559	474	481		443	629	460	540	419	1523[5]	634
							2013							
Seed[1]	81	86	72	90	90	77		90	81	81	81	81	86	81
Fertiliser[2]	116	258	135	124	149	156		113	99	123	142	123	156	153
Herbicide[3]	61	19	27	21	75	47		62	86	82	49	52	54	44
Insecticide	0	0	0	0	0	0		0	0	0	0	0	0	0
Fungicide	0	22	7	14	16	2		0	0	6	13	19	32	19
Fixed[4]	147	169	157	147	169	169		137	147	157	181	147	179	137
Total	405	554	398	396	499	451		402	413	449	466	422	507	434

[1]Includes seed dressings and inoculants, [2]Includes seedbed and in-season fertiliser applications, [3]Includes pre and post emergence herbicides and adjuvants, [4]Includes sowing, fertilising, spraying and harvesting operations, [5] Includes subsoil manure treatment.

Results and Discussion

Team D and J achieved the highest 3 year rotational gross margins at the respective Inverleigh and Lake Bolac sites, achieved largely from high returns during the pulse crop in the sequence (Table 2). Teams that decided to brown manure or achieved low yielding or failed pulse crops largely resulting from poor weed

control in year 1, experienced lower rotational gross margins. Generally higher yielding crops translated into higher gross margins, with the exception of Team L who chose to subsoil manure before planting the second crop in the sequence, a costly operation that negatively affected income.

Effective weed control and timely fungicide treatments in the first crop (2011) at both sites strongly influenced pulse yield and gross margin. At Inverleigh, pulse yields were higher where post emergence herbicides were applied to control wild radish. Weed control at Lake Bolac was entirely dependent on incorporating pre-emergent herbicide at sowing; teams opting to spray later were unable to control annual ryegrass populations that were resistant to some in-crop herbicide treatments, resulting in unplanned brown manure and silage crops.

Table 2. Yearly grain yield (GY) and yearly and rotational (3 years) total cost (TC) and gross margin (GM) for each team at Inverleigh and Lake Bolac from 2011 to 2013, in south west Victoria.

Team	2011 Pulse				2012 Canola				2013 Wheat				3 Year	
	Crop	GY t/ha	TC $/ha	GM $/ha	Variety	GY t/ha	TC $/ha	GM $/ha	Variety	GY t/ha	TC $/ha	GM $/ha	TC $/ha	GM $/ha
							Inverleigh							
A	Faba Bean	2.77	526	277	Hyola 555TT	3.05	472	1295	Bolac	7.06	405	1403	1403	2975
B	Faba Bean	0.00[A]	376	-376	Hyola 971CL	3.44	452	1460	Elmore CL+	5.64	554	1124	1382	2208
C	Faba Bean	4.11	569	653	Hyola 575CL	3.10	456	1308	Phantom	5.7	398	1038	1423	2999
D	Lupin	3.46	374	543	Hyola 575CL	2.83	559	1003	Revenue	7.38	396	1853	1329	3399
E	Field Pea	2.28	415	332	Hyola 555TT	2.47	474	914	Beaufort	5.37	499	774	1388	2020
F	Field Pea	2.26	426	191	Hyola 575CL	2.88	481	1105	Phantom	5.97	451	1120	1358	2416
							Lake Bolac							
G	Faba Bean	2.06	573	24	Hyola 505RR	2.45	443	960	Scout	6.30	402	1338	1418	2322
H	Faba Bean	0.00[B]	368	-368	Thumper TT	2.39	629	628	Beaufort	3.70	413	462	1410	722
I	Faba Bean	3.08	606	287	Crusher TT	2.37	460	821	Phantom	5.06	449	884	1515	1992
J	Faba Bean	4.05	626	562	Hyola 555TT	2.36	540	767	Phantom	5.64	466	1117	1632	2446
K	Lupin	1.59	318	103	Garnet	2.50	419	1050	Revenue	6.18	422	1220	1159	2373
L	Field Pea	1.45	326	-154	Cougar RR	3.51	1523[D]	228	Revenue	7.17	507	1247	2356	1321
M	Field Pea	0.00[B]	371	0[C]	Taurus	2.07	634	652[E]	Phantom	5.96	434	1141	1439	1793

[A]planned brown manure, [B]failed crop due to inadequate weed control, [C]includes income from silage cut, [D]subsoil manured treatment, [E]includes income from grazing over summer.

Financial returns from canola and wheat at both sites were largely driven by robust herbicide programs that minimised weed pressures, along with conservative N fertiliser applications and longer seasoned variety selection. Weed control strongly influenced crop performance and returns, with wild radish control at Inverleigh crucial in the 2012 canola crops and herbicide resistant annual ryegrass at Lake Bolac affecting wheat yields in 2013. Ineffective weed control was observed in Team E at Inverleigh, who applied Atrazine post emergent but did not follow up with a second application later in the season, resulting in unsatisfactory wild radish control and a 20% reduction in canola yield. At Lake Bolac in 2013 there were three failed wheat crops (data not shown) due to poor weed control; crops were overrun by annual ryegrass with weed biomass exceeding 6 t DM/ha. Generally teams applied conservative rates of N fertiliser, most underestimating demand especially in the 2013 wheat crop, when grain protein levels were well below 11.5%. Several team captains expressed concern that the pre-sowing deep soil testing over-estimated plant available N levels, although at Inverleigh Team B outlaid an extra $100/ha on N fertiliser in the wheat crop compared with any other team, with no measurable yield or quality advantage at a loss of income. The choice of the long seasoned and historically high yielding wheat variety Revenue, increased returns at both sites in a season receiving above average spring rainfall. Forward grain marketing didn't play a significant part in the outcome of the competition in the first or second year. In 2013 some Inverleigh teams lost inconsequential amounts from theirgross margin due to poorly timed forward sales. Team L at Lake Bolac oversold their final wheat yield, losing $165 from their 2013 wheat gross margin.

The cost per tonne of grain produced ($/t) was a highly significant ($P<0.001$) indicator of financial returns from each crop in the sequence (Figure 1). Cost structures across all teams were similar (Table 1) with the exception of Team L, whose investment into subsoil manure was not offset by subsequent yields and returns from canola and wheat (Table 2). Subsoil manure is likely to provide longer term yield responses (Sale *et al*. 2012) and a three year study insufficient time to assess the economic merits of this strategy; furthermore other trials have found the Lake Bolac soil less responsive to manuring perhaps from low subsoil clay

contents. Nonetheless, the additional cost incurred by Team L's decision to subsoil manure, meant that the cost per tonne of grain produced was a better predictor of gross margin than simply grain yield.

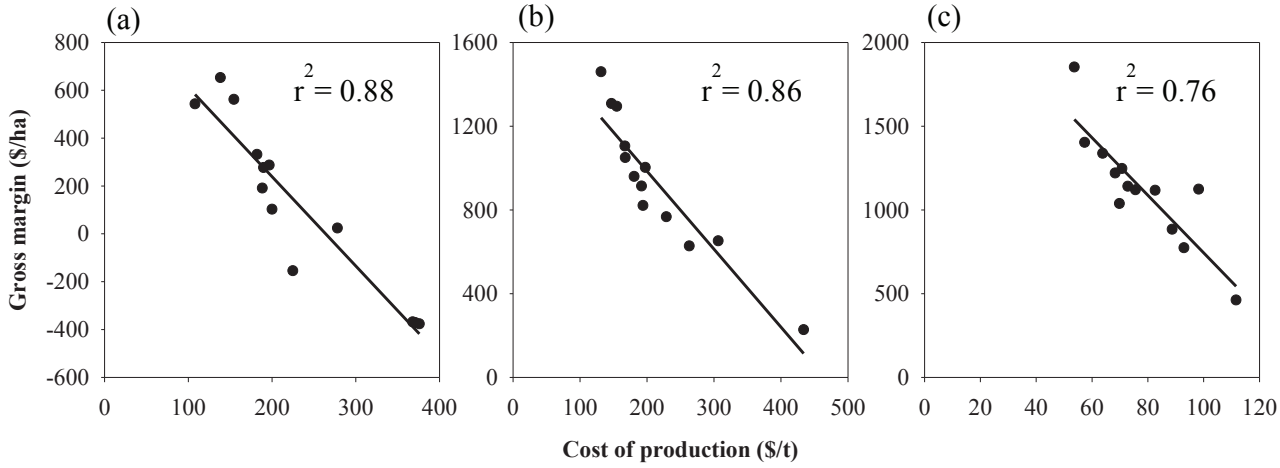

Figure 1. Relationship between the cost per tonne of grain produced and gross margin in the pulse (a), canola (b) and wheat (c) crops, at Inverleigh and Lake Bolac in south west Victoria.

Conclusion

Crop competitions showed large variations in returns, despite all teams growing identical sequences of crops on the same soil types and receiving the same amounts of rainfall at the respective Inverleigh and Lake Bolac sites. The teams achieving the highest financial returns were those that produced high yielding crops whilst minimising their costs of production, reducing weed pressures through effective herbicide programs, combined with conservative in-crop N fertiliser applications and choice of longer seasoned wheat variety suited to above average spring rainfall received in 2013.

Acknowledgements

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Simulating grain and grazing yield of diverse canola cultivars in the high rainfall zone

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Abstract
Recent expansion of cropping into Australia's higher rainfall zone (HRZ) has involved dual-purpose crops suited to long growing seasons that produce both forage and grain. Early adoption of dual-purpose cropping involved cereals, while dual-purpose canola can provide grazing and grain and also a break crop for cereals and grass-based pastures. We simulated grain yield and grazing potential of canola (at 25 DSE/ha until bud-visible stage) for 4 cultivars sown fortnightly from early March to late June at 13 locations across the Australian HRZ over 50 years using APSIM. The cultivars represented winter, winter × spring intermediate, slow-spring, and fast-spring phenology-types which differed in response to vernalisation and photoperiod. Overall there was significant potential for dual-purpose use of winter and winter × spring cultivars at all locations. Mean predicted yields exceeded 4.0 t/ha at most locations. Winter cultivars sown early (March to mid-April) provided most forage (> 2000 DSE.grazing days/ha) due to the extended vegetative stage linked to the high vernalisation requirement. At locations with Mediterranean climates, low frequency of early sowing opportunities before mid-April (<30% of years) limited the utility of winter cultivars. Winter × spring cultivars with an intermediate phenology had a longer, more reliable sowing window, high grazing potential (up to 1800 DSE.days/ha) and high grain yield potential. Yields of spring cultivars were similar to those of longer season cultivars although they provided less grazing (300-700 DSE.days/ha). The simulations emphasised the importance of early sowing, adequate N supply and sowing density to maximise grazing potential from dual-purpose crops.

Key words
APSIM, dual-purpose, phenology, frost, heat

Introduction
A long history of experiments and experience in grazing dual-purpose cereals on mixed farms in southern NSW has provided robust "best-bet" management guidelines for growers and their advisors (Dove and Kirkegaard, 2014). Dual-purpose use of canola in traditional medium rainfall areas has also been demonstrated more recently (Kirkegaard *et al*. 2012) and there is further interest in new areas in the traditional livestock-focussed HRZ. Validated crop simulation models can predict forage production, crop development and yield for a range of sites, seasons and management – and thus expand the insights we can get from specific experiments and experience. We used existing experimental and on-farm data to parameterise the APSIM model to predict crop and livestock production of dual-purpose canola crops. The aim was to evaluate livestock and grain production from dual-purpose canola at 13 representative locations spanning Australia's HRZ. The analysis accounts for differences in soil types and climate to predict frequency of important drivers such as sowing opportunity, forage production for grazing, the risk of frost and heat stress and crop yield. Impacts of management factors such as sowing date, cultivar choice, planting density and N fertiliser application were also investigated and are discussed in full in Lilley *et al.* (2015).

Methods
Canola crop grain yield and grazing was simulated over 50 years at 13 locations distributed across Australia's HRZ using representative soils and long-term climate records from each location. The soil and crop modules from the Agricultural Production System sIMulator (APSIM) were configured in combination with the GRAZPLAN animal models (Holzworth *et al*. 2014) to simulate potential sheep grazing, and ungrazed crops were used to predict potential grain yield. At all locations a factorial simulation analysis was conducted with nine sowing dates simulated at 2-weekly intervals from 8 March to 28 June, and 4 different cultivars representing slow-winter (e.g. Taurus), winter x spring intermediate (e.g. CBI406), slow-spring (e.g. 46Y78) and fast-spring (e.g. Hyola50) phenology types. For each scenario, single year simulations were run for each of 50 years (1959 to 2009) using local Patched Point climate data from the SILO database (Jeffrey *et al*. 2001). Soil water content at sowing varied with season, however the top 30 cm was assumed wet at sowing to separate the effect of crop establishment from sowing opportunity. Standard sowing density was 60 plants/m^2 with soil N set at 250 kgN/ha at sowing and 100 kgN/ha was applied post grazing.

A factorial analysis including 3 levels of N availability and 4 plant densities is described in Lilley et al. (2015). Because many of the sowing date x cultivar scenarios resulted in flowering outside the optimal window, the risks of frost and heat stress were estimated by categorizing low and high temperature occurrences into mild, medium and severe stress events (Table 1). Using the frequency and intensity of these events that occurred during the critical phenological period around flowering, 'safe' sowing windows for each phenology-type at each location were identified which minimised risk of heat and frost events. Where frost or heat events occurred during sensitive stages of development, a yield reduction factor was applied for each day of stress as stress events such as these are not accounted for by APSIM (Table 1). A supplementary analysis of sowing opportunity provided information on the likelihood and riskiness of sowing on specific dates and is reported by Bell *et al*. (2015).

Grazing was simulated using sheep grazed at 25 DSE/ha. Grazing began when the crop reached a biomass of 1000 kg/ha and ceased when either 1) crop biomass fell to 400 kg/ha or 2) the crop reached bud visible, when yield development is sensitive to grazing. The simulated crop was topdressed with 100 kg N/ha after grazing. Grain yield was determined from simulations of ungrazed crops as the grazing management rules applied in this simulation study have been repeatedly shown to have limited impact on crop grain yield.

Table 1. Minimum and maximum temperature criteria for frost and heat stress during phenologically sensitive stages and estimated yield reductions caused. Yield reductions were calculated for each day and accumulated (multiplicatively), so that increasing numbers of stress events, resulted in cumulative reductions in the yield.

Stress	Level	Daily temperatures (minimum/maximum)	Sensitive stage	Yield reduction per day
Frost	Mild	0 to 2°C	140 to 800 degree.days	0%
	Moderate	-2 to 0°C	(2-8 weeks) after flowering	2%
	Severe	< -2°C	commenced	10%
Heat	Mild	30 to 33°C	0 to 630 degree.days	10%
	Moderate	33 to 36°C	(for approx. 6 weeks) after	18%
	Severe	> 36°C	flowering commenced	35%

Results and discussion

Sowing opportunity

At all locations there was an opportunity to sow all phenology types and to achieve some grazing and grain yield (summarised in Figure1). In the Mediterranean locations (WA and SA), the probability of sowing a slow-winter cultivar was small, however there was more opportunity to sow a winter x spring cultivar (30-41%). At northern locations there was a 28% chance of sowing a winter cultivar and 46 to 57% probability of sowing a winter x spring cultivar. For the south-eastern locations, the probability of sowing either a winter type (43-78%) or winter x spring intermediate (70-90%) was much greater than western or northern locations. At all locations there was a high likelihood (62-100%) of an opportunity to sow a spring type.

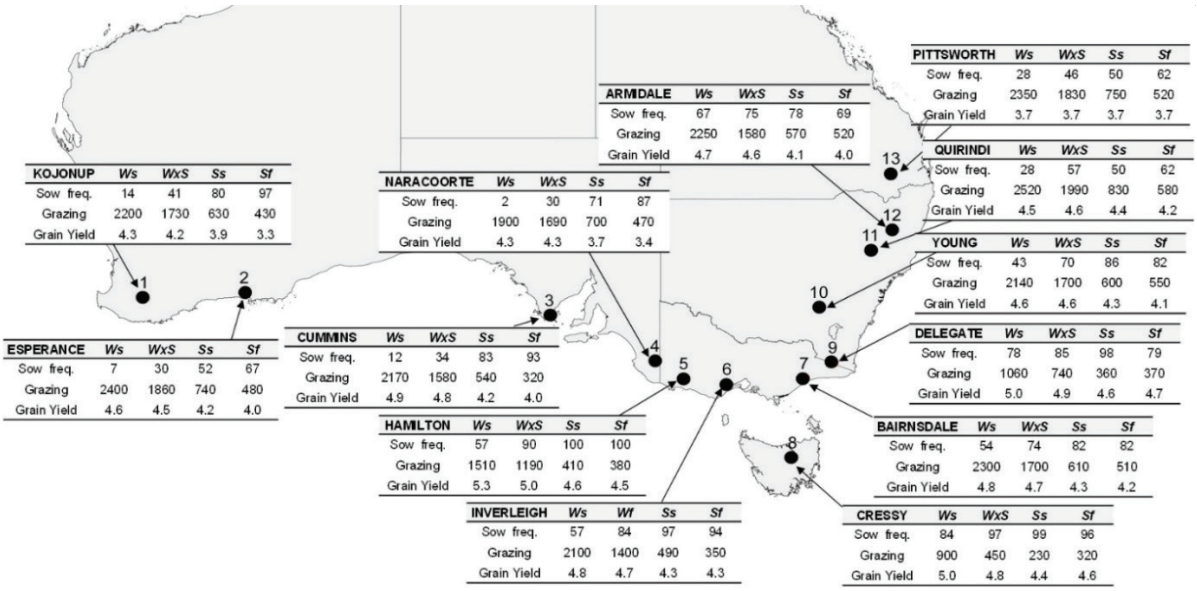

Figure 1. Simulated potential grazing days (DSE.days/ha), potential grain yield (t/ha) and probability of a sowing opportunity (% of years) for predicted safe sowing windows for 4 canola phenology types (Ws – slow-winter; WxS – winter x spring intermediate; Ss – slow-spring; Sf – fast-spring) for 13 locations across Australia's HRZ.

Grain and grazing potential

Winter cultivars produced an average of 900 to 2520 DSE grazing days/ha depending on location, while spring cultivars only produced up to 830 DSE grazing days/ha (Fig. 1). Grain yields of 3.3 to 5.3 t/ha were simulated for all cultivars sown in the optimal window. Early-sown, slow-winter cultivars tended to have the highest long-term average yield at each site, although selecting an alternative cultivar when sowing was delayed only reduced grain yield by up to 1.0 t/ha.

Simulated grain yields were in the range reported in experiments by others (Christy *et al*. 2013, Kirkegaard *et al*. 2012, Sprague et al. 2014, Zhang *et al*. 2006). The adjustments made to yield to correct for the significant effects of heat or frost stress were essential to this study to realistically simulate yield of canola sown at a time when flowering occurs outside of the optimal flowering window. The stress factors applied to reduce grain yield were tested against a very limited dataset and further refinement of these relationships is currently an area of further research.

Simulated grazing biomass was also in the range reported in experiments by others (Kirkegaard *et al*. 2008, 2010, 2012, Sprague *et al*. 2014, 2015). In agreement with the study of Kirkegaard *et al*. (2012), grazing biomass declined significantly with later sowing (eg Fig. 2), due to shorter duration of the period of biomass accumulation before the crop was locked up to avoid damage to the developing bud, as well as the colder and consequent slower growth rate when crops are sown later. Sowing at the earliest opportunity clearly maximises forage production, however, both N nutrition and plant density influenced forage production and grazing potential (Lilley *et al*. 2015). Their analysis showed that a plant density of 60 pl/m^2 and soil N levels at sowing of 250 kg N/ha for winter types and 150 kg/ha for spring types maximised grazing biomass. In grain-only crops, where the canopy growth may need to be controlled to avoid excessive growth and water-use, the optimum density and starting soil N levels may be lower and topdressing a more optimal strategy.

To exemplify seasonal variability in grazing and yield outcomes, Fig. 2 summarises data for one site (Young, NSW) for the slowest and fastest cultivars across the full range of sowing dates. The simulation results show that forage production is much less variable year-to-year than grain yield and declines more rapidly with later sowing than grain yield. At Young, median grain yield of the slow-winter cultivar is stable over the first sowing dates, before declining, however the variability steadily increased during the season, with an increasing proportion of low yields. From May onwards, although the winter and fast-spring types had similar grazing potential and maximum yield, the median yield of the spring type was greater and less variable from year-to-year. For the fast-spring type, there is a clear optimal sowing period from mid-April to mid-May, where yield is maximised and variability is low. For this cultivar, early sowings are likely to encounter frost and late sowings encounter heat stress. At other less frost- and heat-stress prone locations yield variability was much lower (Lilley *et al*. 2015).

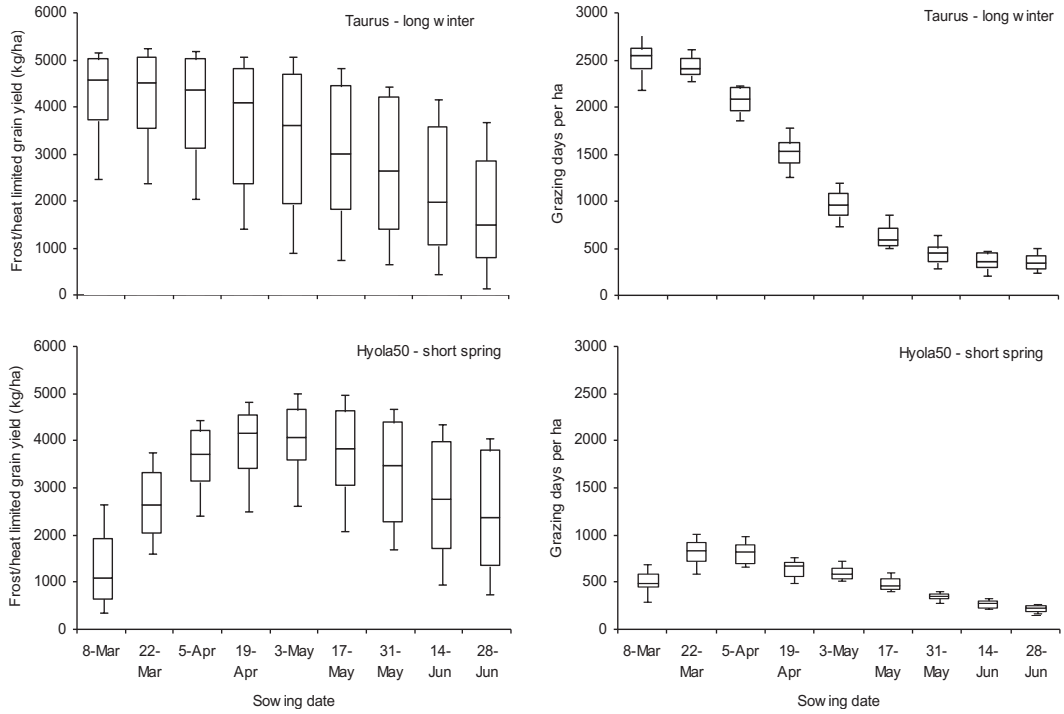

Figure 2. Effect of sowing date on predicted grain yield (left) and grazing (right) for slow-winter and fast-spring canola cultivars at Young, NSW. Boxes show median, 25 and 75% outcome and whiskers 10% and 90%.

Simulation showed that the intermediate winter x spring phenology type was well adapted to April sowing with a similar yield and grazing potential to the winter type, but reduced variability (Lilley *et al*. 2015). This finding is supported by the studies of Kirkegaard *et al*. (2010) and Christy *et al*. (2013) and demonstrates significant potential for a winter x spring intermediate cultivar for dual-purpose and grain-only use in the HRZ.

Conclusions

Expansion of cropping into Australia's high rainfall zone offers significant potential for the use of dual-purpose crops such as canola which offer an alternative to grass-based pasture and cereal crops. Crop simulation predicts significant opportunity to successfully use dual-purpose canola crops throughout the high rainfall zone, with average grain yields of 3.3-5.3 t/ha and 900-2500 days of sheep grazing per hectare. Early sown, long-season winter types offer much greater grazing potential than spring types, while grain yield of different phenology-types is similar when the appropriate sowing dates are selected.

Acknowledgements

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Turning sowing times on their head- spring sown winter habit canola and wheat in a mixed farming system

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Abstract
Diversification in a farming enterprise is an essential risk management tool that has led to many cropping farmers in southern Australia high rainfall zone (HRZ) incorporating livestock into their business. With an increasing area of land being sown to canola every year, the ongoing fit for livestock is becoming a juggle. The introduction of European long season winter type canola varieties into Australia has enabled growers to take advantage of the strong vernalisation requirement in these varieties by sowing earlier, in some cases out of season and effectively getting two crops from the one sowing pass. Sowing in spring and treating the canola as a forage rape over the summer and autumn months, providing large amounts of high quality feed, before removing livestock and carrying the crop through to harvest with no yield penalty, has a niche fit in many mixed farming operations in the region. More recently, winter habit wheat has also been sown in spring, survived the summer and harvested for grain 13 months later.

Key words
Dual purpose crops, grazing, sheep, early sowing, southern HRZ

Introduction

Grazing cereals has proven to be a major opportunity for mixed livestock and cropping farmers in Southern Victoria. If managed correctly, the crop can provide ample amounts of forage over winter and go on to produce grain without a penalty on yield. With more and more land sown to canola in the high rainfall zone (HRZ), finding the fit of canola in a mixed farming system has been the focus of more recent research. Sprague et al (2014) reported that sowing long season winter canola varieties in early autumn and grazing into winter in southern NSW can be very successful, however in southern Victoria, dry autumns and delayed stubble burning can make an early autumn sowing difficult. It is the vernalisation requirement that prevents these winter habit crops from bolting, and essentially means they can be sown in the spring of one year and will not have their vernalisation requirement met (and will not turn reproductive) until a prolonged cold period experienced over winter.

Establishing the crop in spring, carrying it through as a forage crop until autumn before locking it up for grain harvest is proving to have many management advantages for southern high rainfall growers, particularly those who also run livestock (Paridaen & Kirkegaard, 2015). With slugs remaining a huge threat to autumn sown canola crops in the southern HRZ, having an established spring sown crop in the period of high slug pressure has great appeal to growers battling these pests. Having access to high quality green feed in the traditional 'feed gap' of perennial pastures and still being able to harvest grain is what makes this rotation of great interest to the mixed farmers in the southern HRZ.

Method

In November 2011, a replicated field trial was sown at Dunkeld in Victoria's south west to investigate the best management for a spring sown dual purpose canola. Plots were 12m by 2m and sown into an area of failed barley (waterlogged). Treatments were replicated four times, in a randomized complete block design with factorial analysis (number of grazings x grazing intensity) resulting in three grazing durations and two grazing intensities (light and heavy). A light grazing involved the removal of newest leaves, often leaving older leaves intact. Heavy grazing was grazed down to stalks with no dry matter remaining. Grazing management of the crop is outlined in Table 1, detailing the dates of the three grazings as well as the dry matter consumed during this time. The trial was grazed for 55 days in total, with grazing commencing at the end of January 2012 and ceasing at the start of May 2012. The area was grazed by dry ewes at a stocking rate of 34 DSE/ha. After grazing was completed, the gate was closed and the trial was left to grow into a grain producing crop and direct headed at crop maturity.

November 2012 saw another trial sown at Gnarwarre, Victoria to further investigate the viability of the rotation. 12m x 1.6m plots were replicated four times using a randomised complete block design with a two way factorial analysis (variety x grazing). Grazing occurred on the grazed treatments at the end of January 2013 and the start of March with the ungrazed plots protected by exclusion cages. Forage rape variety, Winfred, was also included as a comparison for summer feed.

Four winter habit wheat varieties were sown at Lake Bolac, Victoria in November 2013 in order to test the theory that they would behave in a similar way to winter canola when sown in spring. A randomised complete block with four replicates of each treatment as a two way factorial (variety x grazing) was fenced and received a single grazing from sheep in April 2014.

Results

Several field experiments have demonstrated that European winter canola types have suitable phenological characteristics to allow for their use as biennial spring-sown crops, providing significant forage (2500 to 4000 kg dry matter per ha) for grazing while remaining vegetative through the summer and autumn and recovering following vernalisation in winter to produce high seed yield (2.5 to 5.0 t/ha). Results for one replicated trial sown at Dunkeld in Victoria's south west are presented below (Table 1).

Field trial 2011/2012 Dunkeld VIC

Grazing commenced at the end of January 2012 following some decent rainfall in the summer to enable the crop to get up and away, with 3000 kg/ha of good quality dry matter available.

Table 1. Dry matter production and grain yield for spring sown Taurus canola at Dunkeld in 2012

Grazing (no).	Intensity of grazing	Grazing times	Days grazed	Total dry matter consumed (kg/ha)	Grain yield (t/ha)
1	Light	31 Jan - 22 Feb	22	494	2.8
	Heavy	31 - Jan - 5 Mar	34	2316	2.5
2	Light	31 Jan - 22 Feb 29 Mar - 5 Apr	29	2763	2.9
	Heavy	31 - Jan - 5 Mar 29 Mar - 10 Apr	46	2944	2.5
3	Light	31 Jan - 22 Feb 29 Mar - 5 Apr 26 Apr - 3 May	36	3488	2.7
	Heavy	31 - Jan - 5 Mar 29 Mar - 10 Apr 26 Apr - 7 May	55	4031	2.4
		LSD $_{(p=0.05)}$			NS
		Sown in Spring, ungrazed			1.9
		Sown in Autumn, ungrazed			2.3

In 2012, grazing over summer increased grain yield compared to no grazing. Sowing in spring with no grazing yielded 1.9 t/ha with optimal grazing yielding 2.7 t/ha. Taurus sown at the conventional time (April) yielded 2.3 t/ha. Observations were that plants that were grazed had branched more and produced a denser canopy with all stems producing pods for grain. Over 4000kg/ha of high quality dry matter was removed through the heaviest grazing, whilst still producing a grain yield of 2.4t/ha.

Field Trial 2012/2013 Inverleigh VIC

The 2013 season was almost completely opposite to 2012, with extremely dry and hot conditions from spring sowing until the break in May 2013. Table 2 indicates that dry matter production was down on 2012 (over a tonne less feed) however the value of the green feed in 2013 would most likely outweigh the extra tonne in the favourable 2012 season.

Table 2. Dry matter production and grain yield for several winter canola varieties sown in spring 2012 and harvested in December 2013, Inverleigh VIC

Variety	Time of sowing	Grazing	Spring estab. (plants/m^2)	Autumn survival (plants/m^2)	Reduction in plants (%)	Summer dry matter (t/ha)	Grain yield, manual harvest (t/ha)
Taurus	Spring	Grazed	47	26	-43%	2.5	4.0
		Ungrazed	42	30	-29%		5.0
	Autumn			8			3.6
Hyola 971 CL	Spring	Grazed	41	28	-28%	2.4	4.6
		Ungrazed	42	28	-28%		5.2
	Autumn			14			4.4
Hyola 930	Spring	Grazed	42	26	-38%	2.2	4.9
		Ungrazed	39	36	-4%		5.2
	Autumn			11			4.1
CB 143 CL	Spring	Grazed	43	24	-44%	2.3	4.2
		Ungrazed	38	30	-18%		4.5
	Autumn			17			3.9
CB Sherpa	Spring	Grazed	38	24	-35%	2.8	4.7
		Ungrazed	43	27	-36%		5.2
	Autumn			Not sown			-
Winfred rape	Spring	Grazed	62	31	-49%	2.8	-
LSD $_{(P=0.05)}$			12	7	NS	NS	0.8

Spring sown winter wheat field trial 2013/14, Lake Bolac VIC

Four winter habit wheat varieties were sown in order to test the theory that they would behave in a similar way to winter canola when sown in spring. Results are displayed in Table 3, showing that all varieties whether grazed or not, provided a grain harvest of 3t/ha or over as well as summer feed around 750-800kg DM/ha.

Table 3. Grain yield, protein and dry matter of spring sown wheat varieties at Lake Bolac, VIC

	Grain yield (t/ha)	Protein (%)	Dry matter (kg/ha)
Revenue, grazed	3.3	11.2	750.0
Manning, ungrazed	3.3	10.5	-
Einstein, grazed	3.3	12.1	793.5
Frelon, ungrazed	3.2	12.3	-
Revenue, ungrazed	3.2	10.8	-
Frelon, grazed	3.1	12.0	810.0
Manning, grazed	3.0	12.4	813.6
Einstein, ungrazed	3.0	11.4	-
LSD $_{(p=0.05)}$	NS	0.9	-

Deciding how hard to push the crop at grazing depends on the value of the feed, how the season is going and an individual's attitude to risk. Every grower will have a point at which they feel the benefits and risks are balanced. We aimed to push the crop at different levels to find a 'best bet' and also have a 'worst case' scenario. In 2012, the number of times the crop was grazed had a small effect on yield. Grazing twice produced the best result, yielding 0.1 t/ha more than grazing once and 0.2 t/ha more than grazing three times. Although there was a yield penalty by grazing three times compared to two times, the third grazing supplied

an additional 1000 kg/DM/ha of high quality feed at the beginning of May. Heavy grazing reduced yield compared to light grazing irrespective of the number of times it was grazed. However the reduction in yield was small and the heavy grazing produced 4000 kg/DM/ha of feed compared to 1400kg/DM/ha when lightly grazed.

When deciding on stocking rate and grazing intensity, there can be a trade-off between the value of the feed over summer and autumn and final grain yield suggesting that attitude and preference will vary between growers. Crop stands thinned by 20 to 30% during summer, and this was exacerbated by grazing, but surviving stands of around 30 plants /m^2 were sufficient to support high yields.

At Gnarwarre in 2013, there were no significant differences within varieties when looking at yield under spring and autumn sowing except for Taurus which came from a seed source of very low germination. Sowing in spring, whether there was grazing or not, had no role in the final yield performance. The spring-sowing approach has potential to replace the existing forage rape-spring cereal sequence, or to add a further option to the existing autumn-sown winter canola in areas such as southern Victoria, where early autumn establishment can be problematic and spring-sown crops can better withstand attack by pests and winter water-logging that limits yield of autumn-sown crops. Spring sown canola provides an established and resilient plant stand come autumn which is a major drawcard in slug prone paddocks. The plants are at cabbage stage when slug activity is at its peak and risk of plant damage or loss is very low and input costs markedly less.

Somewhat surprisingly, winter wheat behaved very similarly to winter canola when sown in spring and carried over summer with grazing occurring early autumn. Although the summer was hot and dry, the wheat managed to survive and continued to tiller once the autumn break arrived. At harvest, grain yields of the spring sown wheat averaged 3.2t/ha.

This work has seen canola and wheat withstand some of our hottest, driest summers and still perform well. Given these crops can sometimes struggle to establish and grow well in our wet cool autumns, spring sowing allows these plants to display just how tough they can be.

Take home messages

- Winter habit canola has been successfully sown in spring, grazed over summer and harvested for grain in 2012, 2013 and 2014
- Establishing canola in spring means larger, more resilient plants in autumn with less impact from slugs and waterlogging
- Forage value comparable to commercially available dedicated forage rapes over summer and autumn with added benefit of oil seed production
- Grazing management and timing of stock removal is proving to have an impact on grain yield
- Vernalisation means that winter wheats could be used in the same way

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Using broadleaf crops to improve wheat grain yield and on farm profitability

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Abstract
Broadleaf species are included in cropping systems to improve soil nitrogen (N) fertility, manage difficult weeds and reduce cereal disease incidence in crop rotations. A 4-year crop sequence experiment was conducted at Wagga Wagga to quantify the yield benefit of break crops (canola, field pea, lupin, vetch and high density legume pasture) to wheat crops in subsequent years. Results showed that grain yield increased significantly for the first wheat crop following any break crop that was brown manured. The benefit of break crops diminished in the 2nd and 3rd wheat crops although the grain yields tended to be higher under brown manured treatment. The yield benefits to subsequent wheat crops derived from legumes were compromised when harvested for grain or cut for hay. Overall, the N benefit from legumes was greater than, or equivalent to, fertiliser N (75 kg N/ha) for at least two wheat crops after break crops. Averaged across 4 years, the rotation with canola had the highest gross margin (average $500/year), and treatments that were brown manured were the lowest (average $259 - $289/year) due to income loss in year 1. The brown manured treatments, however, offer opportunities to manage herbicide resistant weeds and reduce the risk of diseases and provide significant N benefits.

Key words
Crop sequence, financial benefit, gross margin

Introduction
Including break crops into rotations with cereals can influence the nitrogen (N) dynamics of cropping systems (Peoples et al. 2001) and assist in the management of weeds and reduce disease incidence in crop rotations (Kirkegaard et al. 2008). However, the high input costs for canola and fluctuating grain prices of pulses give farmers an impression that broadleaf crops are high risk and not as profitable as cereals (Seymour et al. 2012). Indeed, some of the management options, such as brown manuring, will result in no income for a year. The question is whether the subsequent yield benefits obtained after break crops is sufficient to offset any reduction of income resulting from their inclusion in a cropping sequence. A 4-year crop sequence experiment was conducted at Wagga Wagga in 2011-2014, focusing on the rotational benefits of break crops for subsequent cereal crops. Gross margin analysis was also conducted to assess the potential beneficial impacts of break crop on the longer-term financial performance of grain cropping.

Materials and methods
There were 3 sets of treatments phased across years with a single break crop and double break crops, followed by two wheat crops in subsequent years, with a range of combinations of crop sequences contrasted with continuous cereals as a control (Table 1). The break crops used were canola, lupins, field peas, vetch, high density legume (HDL) pastures. Break crops, including canola, were used once over 4 years for the single break crop treatments, and twice in double breaks, i.e. one year with canola and one year with pulses or HDL pastures over 4 years. Wheat was used in the continuous cereal control treatment and was grown with and without N fertiliser (25 kg N/ha at sowing and 50 kg N/ha top-dressed). Field pea was brown manured at peak biomass or harvested for grain at maturity, vetch and HDL pastures were cut for hay or brown manured at peak biomass, while lupin and canola were harvested for grain only.

Gross margin analysis was conducted as per Farm budgets and costs from NSW Department of Primary Industries (Anonymous 2014). The input prices and output prices for all crops were 5-year average from 2009-2013 with urea at $652/t, single superphosphate at $387/t, wheat at $225/t, canola at $452/t, pea at $271/t and lupin at $310/t. The calculation of gross margin for vetch hay was adopted from the high density legume (Hay) budget, but used herbage dry matter yield from the site in corresponding years.

Table 1 Outline of treatments at the Graham Centre site, Wagga Wagga, NSW

	2011	2012	2013	2014
Single break	**Break crops**	Wheat	Wheat	Wheat
	Wheat+N	**Break crops**	Wheat	Wheat
Double breaks	Canola+N	**Break crops**	Wheat	Wheat
	Break crops	Canola	Wheat	Wheat
Control	Wheat+N	Wheat+N	*Wheat+N*	*Wheat+N*
	Wheat+N	Wheat-N	*Wheat-N*	*Wheat-N*

Results and discussion

Impact of break crops on wheat grain yield

The choice of break crop species and end-use both impacted on the grain yield of subsequent cereal crops. For example, the brown manured HDL pasture treatment increased grain yield significantly for the 1st wheat crop compared to the hay cut treatment (3.6 vs 3.0 t/ha, Table 2), although no difference were found between the brown manured and hay cut treatments in the 2nd and 3rd wheat crops. This is consistent to the result from Evans et al. (2003) who found that yields following clover forage conservation crops or green manures exceeded those after pea grown for grain by at least 0.4 t/ha for the 1st wheat crop. The significant increase in grain yield for the 1st crop was most likely due to extra input of N from above-ground biomass under the brown manured treatment combined with a longer period of fallow for N mineralisation and potential recharge of soil water reserves to occur. Nevertheless, the presumed N benefit derived from pasture legumes appeared to last at least 2-3 years as comparable grain yields were achieved to the continuous wheat treatment receiving 75 kg N/ha fertiliser.

When field pea was used as a break crop in year 1, the brown manured treatment increased grain yield at P = 0.055 for wheat, but not canola compared to the pea grain harvested treatment (Table 2). The grain yields of the 2nd and 3rd wheat crops after pea under either brown manured or grain harvested treatment were comparable to the continuous wheat with N fertiliser applied. There were no significant difference in grain yields between brown manured and hay cut treatments under vetch crop (Table 2).

Table 2 Crop yield (t/ha) for different crops under different crop management at the Graham Centre site at Wagga Wagga, NSW

2011	2012	2013&2014	Crop	Grain (t/ha)			
Year 1	Year 2	Years 3&4	Management	Year 1	Year 2	Year 3	Year4
Pea	Wheat	Wheat	Grain	2.5	3.5	3.5	3.5
		Wheat	BM		3.7	4.2	3.5
			Significance		*P*= 0.055	*n.s.*	
	Canola	Wheat	Grain	2.5	2.0	3.7	3.5
		Wheat	BM		2.3	3.7	3.4
			Significance		*n.s.*	*n.s.*	
Vetch	Wheat	Wheat	Hay cut		3.4	3.6	3.5
		Wheat	BM		3.7	3.8	3.6
			Significance		*n.s.*	*n.s.*	
Pasture	Wheat	Wheat	Hay cut		3.0	3.4	3.4
		Wheat	BM		3.6	3.7	3.3
			Significance		*P*= 0.01	*n.s.*	
	Canola	Wheat	Hay cut		1.8	3.7	3.4
		Wheat	BM		2.3	3.7	3.4
			Significance		*P*< 0.05	*n.s.*	
Lupin	Wheat	Wheat	Grain	2.0	3.4	3.6	3.5
	Canola	Wheat	Grain		2.1	3.9	3.4
			Significance		*N.A.*	*P*< 0.05	
Wheat+N	Wheat+N	Wheat+N	Grain	5.2	3.5	3.6	3.4
	Wheat-N	Wheat-N	Grain		2.4	3.1	3.4
			Significance		*P*< 0.05	*P*< 0.05	

n.s., not significant; N.A., not applicable

When lupin was grown, the rotation with lupin-canola-wheat was more productive (and profitable) than rotation with lupin-wheat-wheat (Table 2). For the continuous cereal treatment, grain yields were significantly higher on the fertilised treatments compared with non-fertilised treatment in the 2nd and 3rd years, but not in the 4th year (Table 2).

Gross margin analysis

Rotations with single break crop. Averaged across two phases, the rotation including canola as a single break crop (canola-wheat-wheat or wheat-canola-wheat) had the highest average gross margin ($500/year) across 3 years (Table 3). Cutting for hay significant improved financial return for the rotation with vetch ($425/year) or pastures ($409/year) as a break crop compared to brown manured option, which was comparable to the continuous wheat option with 75 N/ha fertiliser applied. When break crops were brown manured, the gross margin was the lowest ($259 vs $289/year) due to loss of income in the 1st year. The gross margin was intermediate when pulses were harvested for grains ($360-$376/year). The profit/cost ratio was similar for all options (~2:1) except for the sequence with canola as a break crop where the ratio was 2.4 (Table 3). Results indicated that the additional yield benefits derived from the brown matured treatments could not offset the cost of establishment and loss of income. Nevertheless, the brown manure option could offer opportunities to reduce subsequent herbicide costs if it assisted in the control of herbicide resistant weeds (Robertson *et al*. 2010).

Rotations with double break crops. In general, double break crop strategies improved gross margin for all crop end-uses; particularly for the brown manured treatments. The gross margin increased nearly $100/year when canola was used as a break crop in combination with brown manured HDL pastures and field pea compared to rotations with a single break crop (Table 3). Cutting pasture for hay with one canola crop as a double break had the highest gross margin ($465/year), which was similar to continuous cereals with N fertiliser input. Double break crops also offer more opportunities to reduce disease incidence and to control difficult weeds (Lemerle *et al*. 1996).

Table 3 Gross margin analysis under different crop rotation sequence at the Graham Centre site

Crop Management	Treatment	Income	Variable cost	Gross margin	Profit/cost ratio
		Single break			
BManure	Pea	$585	$296	$289	2.0
	Vetch	$553	$295	$259	1.9
	Pasture	$562	$287	$275	2.0
Hay	Vetch	$825	$400	$425	2.1
	Pasture	$811	$402	$409	2.0
Grain	Pea	$714	$354	$360	2.0
	Lupin	$716	$339	$376	2.1
	Canola	$859	$359	$500	2.4
		Double break			
BManure	Pasture	$674	$311	$363	2.2
BManure	Pea	$674	$317	$357	2.1
Hay	Pasture	$863	$398	$465	2.2
Grain	Lupin	$780	$351	$430	2.2
Grain	Pea	$772	$361	$411	2.1
		Continuous cereals			
Grain	+N	$878	$412	$467	2.1
Grain	-N	$663	$333	$330	2.0

Conclusions

The apparent N benefits obtained from legume break crops were comparable to applications of 75 kg N/ha of N fertiliser. The wheat yield benefits derived from brown manured treatments were greater than the same legume treatments harvested for grain or cut for hay. This, however, did not translate to an improved economic benefit over grain harvest or hay cut treatments as the wheat yield increase for brown manuring was insufficient to offset the total loss of income in year 1. The brown manured option could, however, offer opportunities to reduce future herbicide control costs if the paddock contained herbicide resistant weeds. Therefore, the potential benefits from break crops should be fully evaluated by considering opportunistic costs of management of weeds and diseases in addition to any benefits obtained of improved N fertility.

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Planning horizon, commodity price and weed burden influence the number of break crops in a crop sequence

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Abstract
Crop rotation, where one crop or pasture is grown to provide a break from diseases, weeds and replenish nutrients for a subsequent crop is well known. In modern farming systems the intensity of cropping has increased, where cereals may be grown for many years before a break occurs. Here we test how frequently break crops are grown in response to the planning horizon (3 year, 5 year or 10 year) and the price of wheat ($270 /t, $350 /t). We also determined the size of the weed seed bank necessary to change the crop sequence. This weed seed bank was viewed as a break crop trigger. Economic simulations were conducted for the wheat belt of Western Australia using the crop rotation model LUSO. Under high wheat prices, in 3 years, continuous wheat was the most profitable. When the rotation was extended to 5 years, 1 canola break crop was grown. When the rotation length was extended to 10 years, 2 green manure pasture breaks were used. At low wheat prices, in 3 years 1 canola crop was included. At 5 years, 2 canola crops were grown and in 10 years, 2 canola crops and 2 green manure pastures were included in the crop sequence. More breaks were grown when wheat prices were low and the planning horizon was longer. The size of the weed seedbank required to justify growing a break crop declined as the planning horizon increased and the commodity price of the dominant crop decreased.

Key words
Pastures, oilseeds, cereals, crop rotation, optimisation

Introduction

The decision to grow a break crop or cereal crop is complex. At one level, it is widely acknowledged that break crops enhance the yield of subsequent cereal crops by increasing nutrient supply, interrupting disease life cycles and allowing the farmer to use different weed control options (Angus et al. 2015, Seymour et al. 2012, Lawes et al. 2013). However, in many situations, break crops may not appear profitable. For example, in Western Australia, lupins were recently valued at $200/t, and potentially unviable at that price. Similarly, in drier climates, break crop options like canola and chickpeas have failed during droughts. Therefore, simple gross margins would suggest that break crops may be uneconomic, and farmers can generate superior returns by growing continuous cereals, particularly when they appear to be the obvious choice.

Simple gross margins ignore future returns, and intangible concepts such as future weed control costs, the effect of disease and changes to nutrient supply. Managing these intangibles can often lead to improved cereal yields, and higher economic returns for similar or lower levels of input. As a result there is a dichotomy between a crop choice or rotation that maximises immediate economic returns and another that focuses on the longer term economic payoff. This dichotomy is often influenced by commodity prices and the extent of the biotic stresses present in the paddock. Recently, Kirkegaard and Ryan (2104) coined the term “break crop trigger” for defining the biotic conditions when a particular break crop should be grown. It is conceivable that this trigger point could be influenced by the biotic stress, the planning horizon and commodity price of the dominant rotation crop.

We explore the impact the planning horizon, and commodity price has on the number of break crops grown, and consider how these factors alter the trigger point of weeds that force another break to be included in the crop sequence. The crop sequencing model LUSO is parameterised for the Kojonup region in Western Australia.

Methods

We parameterise the Land Use Systems Optimiser (LUSO), for canola, lupins, managed legume pasture, and wheat for the Kojonup region of Western Australia (table 1). LUSO is a bio-economic state and transition model that integrates the effects of weeds, disease, nitrogen dynamics and crop yields. The model determines the optimal rotation from a given set of crop or pasture choices. Each crop or pasture influences the weed populations, disease populations and nitrogen dynamics. The weeds and diseases influence the yields of subsequent crops, while the nitrogen dynamics and weed population influences the cost of managing the crop. The model can be used to explore strategic and tactical management strategies and explore how risky particular rotation sequences are (Lawes and Renton 2010, Lawes and Renton 2015, Renton et al. 2015).

Table 1. Enterprises and economic parameters defined for the LUSO analysis

Enterprise	Yield (t/ha)	Low Price ($/t)	High Price ($/t)	Cost ($/ha)	N requirement (kg/ha)	Weed survival (0-1)
Wheat	3	270	350	250	160	0.05
Lupins harvested	1.5	270	270	200	0	0.05
Sprayed pasture	3	0	0	80	0	0.03
Canola	1.3	550	550	250	120	0.03
Lupins manured	1.5	0	0	150	0	0.03
Pasture	3	90	90	100	0	0.03

Here, we use LUSO to quantify the costs and benefits of including a break crop in the rotation at Kojonup on a sand over gravel soil, where the input parameters are generated via consultation with local growers and the APSIM crop simulation model. The changes in weed population and disease are simulated.

The optimal rotation is evaluated over 3 years, 5 years and 10 years. These optimisations were conducted to determine whether more break crops are selected when the planning horizon increases from 3 to 5 to 10 years with low and high initial weed pressures. Each scenario was run at a high wheat price ($350/t), that would automatically favour an intensive cereal crop sequence and at a low wheat price ($270/t), where the gross margin for wheat is less favourable.

The starting seedbank was increased from the initial population of 50 seeds/m2 at increments of 1 seed/m2 to determine when the starting seedbank brought about a change in the crop sequence. This was defined as the seedbank trigger point, and we evaluated this trigger under low and high wheat prices for the 3 yr, 5 yr and 10 yr rotation sequences.

Results

For the short (3 yr) simulation with low wheat prices, a wheat canola wheat sequence was selected and it generated a cumulative profit of $405/ha. Under high wheat prices a continuous wheat sequence was selected that generated $915/ha (Figure 1). For this particular crop sequence, wheat yields declined from 2.64 t/ha in year 1 to 2.39 t/ha in year 3, The decline in yield occurred because the disease impact from growing continuous wheat increased from 5% in year 1 to 14% in year 3. The losses due to weeds increased from 7% in year 1 to 8% in year 3, and the continuous wheat system left a residual seedbank that increased from 50 seeds/m2 to 305/m2. The decline in wheat yields resulted in a steady decline in annual returns from $364/ha in year 1 to $250 in the final year of the crop sequence (Figure 1). When cereal prices were low, and canola was grown, the steady decline in annual profit did not occur (Figure 1).

For the mid (5 yr) simulation of crop sequences, with high wheat prices, a wheat, wheat, canola, wheat, wheat sequence was selected. After 5 years, this sequence generated a cumulative profit of $1332. Wheat yields declined from 2.64 t/ha in year 1 to 2.50 t/ha in year 2. The canola crop managed the disease, and wheat yields in year 4 and 5 were equivalent to those of year 1 and 2. The weed population, and yield loss due to weeds had increased from 7% in year 1 to 10% by year 5 and at the conclusion of the crop sequence

972 seeds/m2 were returnded to the seedbank. Annual returns declined from year 1 to year 3, when a canola crop was grown. Profits increased after the canola crop before declining again in the final year of the crop sequence (Figure 1). With low wheat prices the crop sequence changed to wheat canola wheat canola wheat. In this scenario, weeds and disease were managed and wheat yields declined from 2.64 t/ha in year 1 to just 2.62 t/ha in year 5. This crop sequence mimicked the start of the 3 year crop sequence.

With the long (10 yr) crop sequence, wheat crops were grown for 3 years, and then a managed pasture, that controlled weeds, was grown. This was repeated, so over a 10 year period, 2 sprayed pastures were grown and 8 wheat crops were grown. This particular crop sequence managed the weed burden until the 10th year, when the seedbank increased to 1300 seeds/m2. Wheat yields were reduced to 2.46 t/ha in the final year of the sequence. The pasture was expensive to grow, and generated a loss of $230/ha. However, nitrogen from the pasture contributed to substantial profits in years 5 and 9 of the crop sequence (Figure 1). With low wheat prices a complex crop sequence of wheat, canola, wheat, canola, wheat, wheat, pasture, wheat, pasture, wheat, was selected. The first 3 and 5 years of this sequence mimicked the sequence selected by the 3 and 5 year simulations. However, after that time, weeds became a problem and were again managed with a sprayed pasture (Figure 1).

Under high wheat prices the optimal crop sequence changed when the starting conditions for the weed seedbank were increased from 50 to 750 seeds/m2 for the 3 year crop sequence. A sprayed pasture replaced the second wheat crop in this scenario. For the 5 year rotation, the canola crop was replaced by a sprayed pastured in the second year when the initial weed seed bank increased from 50 seeds/m2 to 148 seeds/m2. The long term crop sequence altered when the starting seedbank increased from 50 seeds/m2 to 131 seeds/m2. The number of wheat crops declined by 1, and the number of pastures grown increased from 3 to 4. For the low wheat price scenario, a crop sequence change occured when the weed seedbank increased from 50 to 557 seeds/m2 , where a pasture replaced the canola. This switch occured in the 5 yr sequence when the starting seedbank reached 158 seeds/m2. Pasture again replaced canola in the 10 yr sequence when the starting seedbank was 82 seeds/m2. In general, the trigger point to change the crop sequence from the initial solution was influenced by the commodity price of wheat, and the length of the crop sequence. As crop sequences increased in length, the size of the trigger declined.

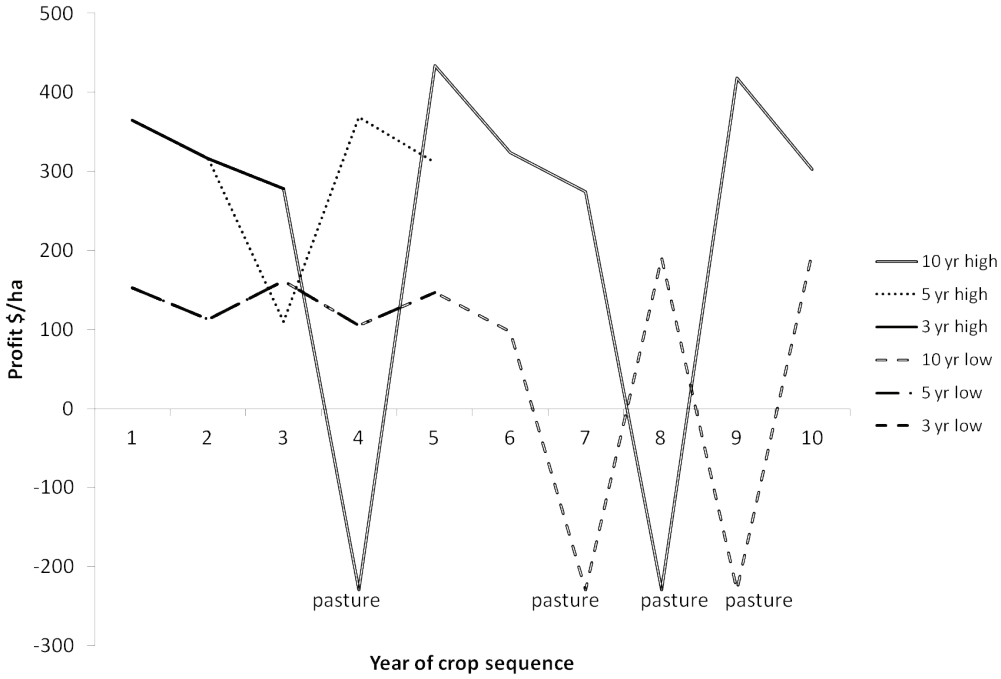

Figure 1. Annual profit in dollars per hectare for the the 3 yr, 5 yr, 10 yr optimal crop sequences with low and high wheat prices. The dominant crop is wheat, and all other crop or pasture choices are labelled.

Discussion and conclusions

The question about whether the optimal crop sequence changes with respect to the length of the planning horizon is dependent on commodity price. Under a low priced regime, the crop sequence for the 3, 5 and 10 year scenarios did not change, until the 10 year scenario moved beyond the 5th year. For this regime, wheat was still the most profitable crop, but the break crop generated profits that were not substantially lower than wheat. The crop sequence did not change until the break crop was unable to control an emerging weed problem. In contrast, under a high priced scenario, each crop sequence differed, where the short term crop sequence was more exploitative than the 5 year scenario, which included a break crop in the 3rd year. The 10 year sequence actually mimicked the 3 year sequence for the first 3 years, before growing a pasture break. Therefore, longer term planning horizons did not necessarily result in a management change. The underlying implication is that if the scale of the biotic stress is understood, short term and long term crop sequences may generate similar economic returns, as the crop sequences selected are initially similar.

The duration of the crop sequence had a far greater impact on the size of the weed seed bank that triggered a change in the crop sequence. In general, a moderate (< 2 fold) increase in the weed seed bank brought about a change in rotation when viewed over a 10 year time horizon. However a massive (> 10 fold) increase in the biotic stress was required to bring about a change in management when viewed over a short time frame. Indeed, the time horizon had a greater impact on this shift in the size of the trigger than the commodity price of wheat. The underlying implication is that to develop the concept of a crop trigger, scientists need to develop reliable estimates about the size of the initial biotic stress, its rate of increase under certain management scenarios and an idea of the time frame the farmer is working too. Long term sequences suggest it is worth keeping biotic stresses low, while short term planning would suggest they can be ignored until they have reached obviously large proportions. These outcomes are dependent on possessing management solutions than can correct large weed seed banks in one year.

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Achieving modelling of pasture-cropping systems with APSIM and GRAZPLAN

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Abstract
Pasture-cropping has the potential to increase productivity in mixed farming systems while also providing the associated benefits of including a perennial pasture species in the system. To determine the potential long-term benefits of pasture-cropping across a range of environments, modelling is required. To undertake this, validation of a mixed farming system model is a necessary first step due to the inherent difficulty in simulating complex system involving interspecies competition. The AusFarm software was used to link modules from APSIM and GRAZPLAN to create a mixed farming system. Simulations of sole crop, sole pasture, and a pasture-crop were evaluated to determine the linked model's ability to represent data from a pasture-cropping field experiment at Wellington, NSW. Across a 3-year time series the model was able to satisfactorily predict sole crop, sole pasture, and pasture-crop production, ground cover, and soil water dynamics. There were, however, periods of over and under-estimation of field data in the pasture-crop simulation, with RSME of the observed mean varying from 3% for grain protein, 19% for grain yield, 13% for soil moisture, 29% for ground cover, and >60% for inorganic soil nitrogen.

Key words
AusFarm, intercropping, soil moisture, pasture, crop

Introduction
Pasture-cropping has been shown to increase productivity (Humphries et al., 2004; Roberts Craig et al., 2013), in addition to providing benefits of increased soil water, summer weed control, and soil structural benefits (Humphries et al., 2004). The number of pasture-cropping studies undertaken in Australia is limited, therefore to evaluate the benefit of pasture-cropping in a range of environments and management systems, systems analysis with mathematical models will be useful. One such model, the Agricultural Production System Simulator (APSIM) has been shown to satisfactorily simulate pasture-cropping field data, in addition to determining the effects of changing management (Harris et al., 2010, Robertson et al., 2004). To further understand this system the model needs to include a grazing component to accurately reflect a mixed farming system. The AusFarm software is able to link modules from APSIM with GRAZPLAN to create a mixed farming system model using the CSIRO Common Modelling Protocol (Moore et al., 2007). This modelling approach has been used to simulate crop-livestock interactions in mixed farming systems (Lilley and Moore, 2009). To determine the potential of pasture-cropping across a range of environments it is first important to determine if the GRAZPLAN+APSIM models can together satisfactorily simulate pasture-cropping field production data together with the associated soil water and nitrogen dynamics.

Methods
Dataset
The experiment was conducted at the Wellington Research Service Centre, NSW, Australia (32°30'S, 148°58'E). The site is 300 m above sea level and gently undulating. The soil is a Red Dermosol (Isbell, 1996), with a 10% gravel component. The A1 surface layer (0-10 cm) has a $pH_{(CaCl2)}$ of 6.5, the B1 horizon (10-30 cm) has a $pH_{(CaCl2)}$ of 6.5, and the B2 horizon has a $pH_{(CaCl2)}$ of 8.1. The annual rainfall is evenly distributed with the long-term average 618 mm; for the experimental year 2005, 2006, and 2007 annual rainfall was 668 mm, 302 mm, and 647 mm respectively. The field experiment (with 3 replicates) involved sowing wheat (*Triticum aestivum* cv. Ventura) into pasture dominated by *Bothriochloa macra*. Experimental details and results are described in full in a previous paper (Millar and Badgery, 2009).

Simulation
The AusFarm program (version 1.7), using APSIM soil components, was characterised based on field conditions from studies conducted by Millar and Badgery (2009) and McNee (2013). Soils were characterised by combining data from both studies (located within 500 m of each other on almost identical soils). The gravel component of the soil was represented by reducing soil bulk density, water content at saturation, drained upper limit, 15-bar water content, and crop lower limit by 10%. The root hospitality

factor (XF) was reduced in the fourth and fifth soil layers to reflect the hostile conditions for root growth below 60 cm. The default decomposition rate of residues in the surface OM module was previously found to require adjusting to accurately reflect the Wellington site conditions (McNee, 2013); the reference decomposition rate was therefore set to 0.055 day^{-1}. To account for the plant-growth-limiting soil phosphorus levels, the fertility index of the pasture species were reduced to 70%. As the cropping component does not have a fertility index function, and there is not a working APISM phosphorus component for wheat or oats, the reduction in plant growth due to low phosphorus was represented through a 30% reduction in crop radiation use efficiency. The simulation was run continuously from 1 Apr 2001 to 30 May 2008, allowing representation of pre-experimental management and the influence of each year on the next.

Evaluation

The evaluation of simulated and observed data was undertaken in two parts. Firstly, the magnitude of difference between the AusFarm simulated and observed field data was quantified using either root mean square error (RMSE), where few data points were available, or root square error (RSE) when there were sufficient data points to undertake this analysis. Secondly, confidence limits (at the 95% level) were calculated for each sampling point, and used to determine whether the simulated output fell within the population distribution. Values outside of the confidence limits were considered over- or under-estimations.

Results

There was variation in the level of agreement between the simulated and observed data (Table 1, Fig. 1 and Fig 2). There was good agreement for grain yield and protein in both the sole crop and pasture-crop, with the relative RMSE of the observed data less than 20% (Table 1). However, agreement was poor between the simulated and observed data for crop and pasture biomass, with relative RMSE 42% and 54% respectively (Fig. 1). The RME for the pasture-crop was 68% for the crop component and 45% for the pasture component. This was due to a low number of periods of over and under estimation (Fig. 1).

The level of agreement for percentage ground cover varied depending on the treatment (Table 1). There was good agreement for the sole pasture and lower level of agreement for the sole crop and pasture-crop. The simulated sole crop and pasture-crop percentage ground cover was overestimated for all years, while sole pasture ground cover was under-estimated in 2006 and 2007 (data not shown). There was good agreement for soil moisture over time in all treatments, with RSE of less than 20% of the observed mean (Table 1). There was a poor level of agreement between the simulated and observed data for both nitrate (Fig. 1) and ammonium (data not shown), with RSE greater than 30% of the observed mean for both nitrate and ammonium in all treatments. In the sole crop and pasture-crop treatments the simulated data for NO3 was under-estimated in all years for approximately half of all measurements (Fig. 2). The simulated nitrate levels for the sole pasture were generally within the confidence limits, with the exception of an overestimation during the 2006 autumn (Fig. 2).

Table 1. Root mean squared error (RMSE) and Root squared error (RSE) between observed and simulated sole crop, sole pasture, and pasture-crop for production and soil water.

	Treatment	Observed Mean	RMSE	RSE	% RMSE/RSE of Mean
Grain yield (t/ha)	s_crop	2.2	0.3		11%
	pasture_crop	1.2	0.2		19%
Grain protein (%)	s_crop	8.5	0.0		0%
	pasture_crop	8.5	0.3		3%
Ground cover (%)	s_crop	0.4		0.2	36%
	s_pasture	0.9		0.1	9%
	pasture_crop	0.4		0.1	29%
Soil moisture (mm)	s_crop	91.0		13.9	15%
(0-600 mm)	s_pasture	90.8		11.4	13%
	pasture_crop	80.2		10.1	13%
(600-1500 mm)	s_crop	155.6		10.6	7%
	s_pasture	132.8		20.8	16%
	pasture_crop	155.6		8.2	5%

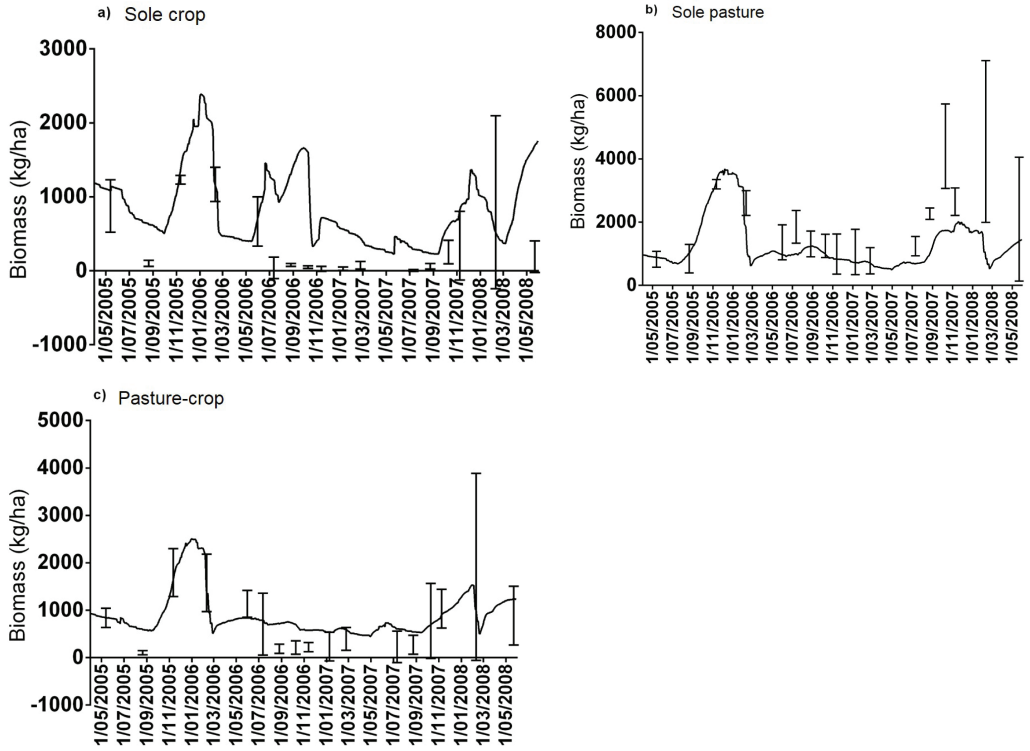

Figure 1. Time series plots of observed mean (scatter plots) and simulated (line) available pasture and weed biomass (kg/ha) in the a) sole crop, b) sole pasture, and c) pasture-crop treatments. Error bars represent the population distribution at 95% confidence limits.

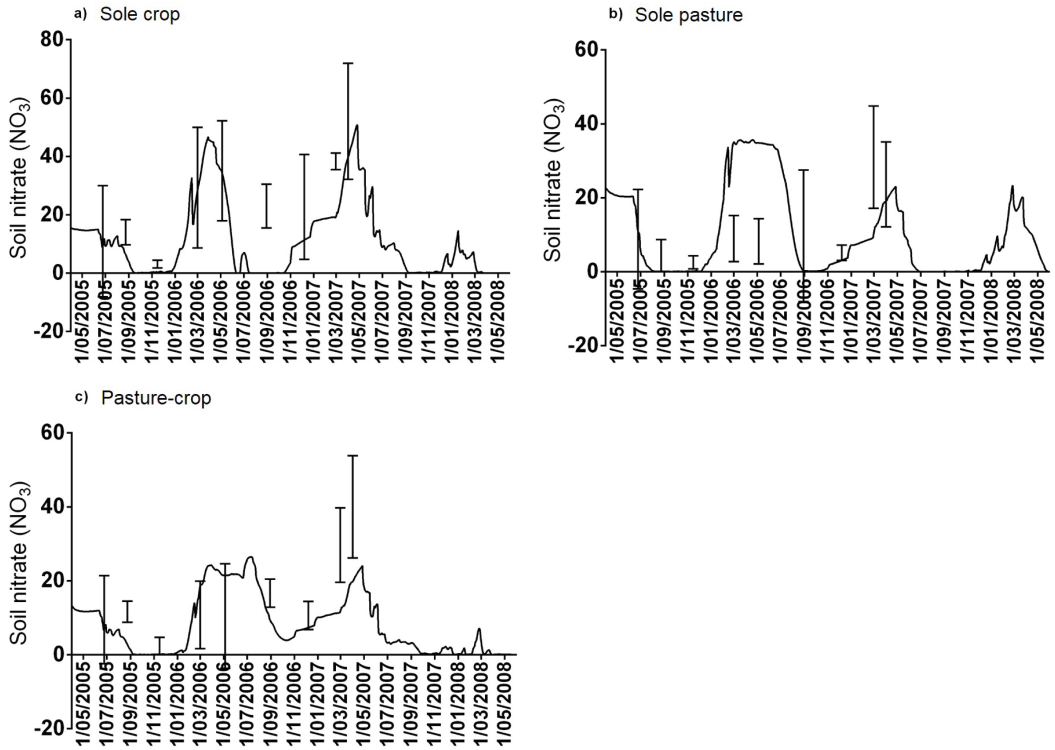

Figure 2. Time series plots of observed mean (scatter plots) and simulated (line) soil nitrate (NO_3) in the a) sole crop, b) sole pasture, and c) pasture-crop treatments. Error bars represent the population distribution at 95% confidence limits.

Discussion

Productivity measures of sole crop, sole pasture, and pasture-crop were generally in agreement between the simulated and observed data. However, there were some periods of over- and under-estimation in the wheat crop biomass, and pasture and weed available biomass. Similarly, previous modelling studies have

also reported periods of over and under-estimation when simulating both sole and pasture-crop systems (Asseng et al., 1998; Harris et al., 2010; Robertson et al., 2004). The model was able to accurately reflect the soil water dynamics of all three systems. Similarly, the APSIM model was found to satisfactorily simulate soil water dynamics of pasture-crop systems (Robertson, 2004). In the current study, the period of over-estimation of soil moisture in 2007 for the sole crop and pasture-crop treatment is likely to be a reflection of the under-estimation of available biomass starting mid to late 2006 and continuing to October 2007. An increase in simulated available biomass during this time is therefore likely to result in a subsequent decrease in soil moisture. The soil nitrogen of the sole crop and pasture-crop systems were often under-estimated in the AusFarm simulation. The simulated nitrogen fluctuations generally followed that of the observed measurements, with periods of under-estimation. The nitrogen dynamics of the sole pasture system generally represented field measurements. The difficulty in accurately simulating nitrogen in pasture-cropping systems has been previously reported in a study using the APSIM model; Harris et al., (2010) found that without resetting soil nitrogen each year in autumn, they could not accurately model the soil nitrogen profile of field results. Similarly, APSIM sole crop simulations were shown to require adjustments to mineralisation rates and carbon to nitrogen ratio in order to achieve satisfactorily agreement of field results at a location close to the current study (McNee, 2013). It is likely that the under-prediction of soil nitrogen had a limiting effect on biomass production in the sole and pasture-crop simulations. This highlights the importance of accurate soil parameters in simulating soil nitrogen dynamics and, in turn, available dry matter.

Conclusion

The AusFarm model was able to satisfactorily simulate sole crop, sole pasture, and pasture-cropping productivity, and soil water dynamics. This agreement of field data indicates this model can be used with confidence in longer-term simulations of pasture-cropping systems in the study region.

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Adding value through pasture and fodder break crops- is the current break crop broken?

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Abstract
Identifying suitable break crop rotations is becoming a major challenge for farmers and advisors in southern Victoria. Canola has traditionally been the main break crop used, but the high input costs, establishment challenges and dry finishes makes it high risk. There is also perception canola yields are declining with its repeated use in the rotation. Weeds, especially annual ryegrass, emerging herbicide resistance, root diseases and the depletion in soil nitrogen are major reasons for seeking alternative break crops to canola. The complexity of rotation selection means that there is no 'recipe' that can be applied broadly. Preference, specific problems to be solved and opportunity need to be considered when making these decisions. Due to this, and the long term nature of some rotational benefits, the problem to be focused upon in this paper will be weeds and the use of pasture and fodder rotations to control weeds and drive down the weed seed bank. Fodder conservation is a practical option for growers in the high rainfall zone of southern Australia. The area still has a vibrant livestock industry and Victoria's largest dairy region is close by. The market for fodder (both hay and silage) exists and is likely to grow. Three years of field experiments have shown that alternative rotations that allow weed removal through grazing or fodder have the ability to reduce weed numbers by 80-90% in two years whilst producing large amounts of feed and in some cases fix nitrogen.

Key words
Rotations, legumes, grazing, south-west Victoria, crop sequencing

Introduction

Finding alternative break crops to canola and determining the appropriate place and application of these alternatives is critical to the longevity of cropping in Southern Australia. Break crops are generally described as a crop grown as an alternative to cereals, usually a broadleaf, for control against weeds and disease. Grain legumes such as peas and beans have been the focus of promising crop sequencing research in recent years, with more suitable varieties being bred and refined management strategies making this break crop more profitable and less risky. The Pastures in Crop Sequencing work concentrates on the role of pastures and fodders in a crop rotation, given the abundance of mixed farming enterprises and the opportunities available in certain regions (dairy etc.).

Three significant variables that influence the type of fodder break crops that may be appropriate at any point in time are **preference** toward livestock, the **problems** that need solving and the prevailing conditions or **opportunities** when the choice needs to be made. There are numerous combinations of species, applications and desired benefits from the break crop phase. This creates a complexity because there is a multitude of 'right answers' depending on an individual farming circumstance. Rotation length and sequencing of break crop options need to be considered, with analysis focusing on the net benefits over time and not simply one crop. Weed control using an Integrated Weed Management (IWM) approach will be the focus of this paper.

Spotlight on weeds

The most common approach to weed control has been to focus on knockdown herbicides early in the season and herbicides mid-season (pre or post emergent). However over the life of this research, our thinking has moved from early and mid-season weed control to also consider control of the weeds later in the season.

Management options early in the season are fairly straight forward and still seem to be quite reliable. It is the late germinating weeds, the ones that strike and mature after the opportunity for in crop herbicide has passed that seem to be carrying over. These late germinating weeds are missing traditional control methods

in the conventional rotation, but have set seed by the time the crop is ready to be harvested. In the continuous cropping rotation adopted, we are selecting for late germinating weeds, leaving ourselves with limited options as to how to remove these weeds from the system.

Seed set control relies on intercepting the seed production of weeds that have survived earlier attempts at control (McGillon and Storrie 2006). Therefore the timing of a seed removal operation is more critical than the method of seed removal, and the use of multiple seed removal tactics will ensure better control.

Method

Numerous trials have been conducted in the past six years where weed populations have been measured. These include tactics applied at pre break (grazing, autumn 'tickle', stubble burn) and in season (time of sowing, species, sowing rate, grazing, fodder conservation, manuring and summer fodder crops). This paper focusses on annual ryegrass (ARG) and three of these tactics;

- Sowing rate
- Duration of break crop
- Species used (and the associated management options these species lend themselves to).

Weeds have been measured six weeks after sowing for three consecutive years across treatments, replicated four times. The trial has been designed as a three way factorial, with sowing rate of fodder crop (common, double and triple), duration of break (1, 2, 3 years) and the species of break crop (clovers, oats, ryegrass, peas, lucerne and nil).

Results and discussion

Weed populations are dynamic and can fluctuate markedly from year to year. This is the result of dormancy strength conferred at seeding, fluctuations in temperature and moisture over summer, timing of the autumn break, predation, depth of burial and if it is grazed (Grundy 2003). In order to conclude that a treatment has altered a population, the results need to be compared to a control treatment. In addition weed populations are often uneven across a site which means there can be large variability even within replicates of the same treatment. This means statistical significance is often not measured, even if the differences appear large. Therefore readers are encouraged to proceed with caution when interpreting results.

Competition arising from sowing rate

There was no significant difference on weed populations or dry matter production at double or triple sowing rates compared to the recommended sowing rate (Table 1). The current 'common' sowing rate of species appears sufficient to provide competition to weeds and optimum dry matter production.

Table 1. Change in annual ryegrass (ARG) populations from June 2012 to June 2013 under three different species sown at common, double and triple sowing rate. Weed numbers are not significant at p=0.05

Species	Sowing rate (kg/ha)	Establishment (pl/m2)	Dry matter (kg/ha)	ARG 2013 (pl/m2)	Change in ARG numbers after one year
Balansa clover					
Common	6	113	5176	19	-89%
Double	12	202	5812	34	-78%
Triple	18	248	4031	19	-90%
Peas					
Common	100	43	5637	23	-89%
Double	200	74	6393	25	-82%
Triple	300	81	4785	26	-81%
Forage oats					
Common	100	187	8802	56	-82%
Double	200	279	7824	23	-91%
Triple	300	447	9681	33	-89%

These results support other pasture research (Burge and Nie 2012) that shows that the only advantage to higher sowing rates is achieving ground coverage faster. A higher sowing rate does not necessarily translate to more dry matter production, or as shown here, a greater reduction in weed populations. If looking to sow at lower rates than recommended, there is a risk that the weed competition may not be sufficient due to low crop numbers and could encourage weed growth.

Duration of break crop
Seed bank dynamics are different between annual ryegrass and wild radish. McGowan (1970) found that with ARG, you could expect 75-85% germination on the first couple of rain events in autumn. Most of the remaining seeds will germinate after June, with about five per cent carrying over to germinate the following year. The weeds we are allowing to go through in a conventional crop (allowing late season weeds to set seed) is almost selecting for weeds that we will never control with pre sow or early in crop tactics. With this in mind, stopping seed set is critical but different thinking needs to be applied to ARG and WR.

Wild radish seed banks appear to be far more difficult to run down due to dormancy and longevity of the seed. Cheam (1996) reported that up to 70% of WR seeds are still dormant at the start of the cropping season, making early season management ineffective on the majority of the population. Continual control of WR should be at the forefront of management decisions to prevent turning a small manageable problem into a bigger one that forces a management change rather than gives a choice.

Focusing on results for ARG at Lake Bolac (Figure 1) suggests that a one year fodder break crop like Balansa clover can reduce ARG by up to 85% (>160 to <25 pl/m^2) when weeds were measured in June (at crop establishment). This high level of control is coming from successful pre sowing and early in crop management, so is it the late season weeds that are causing weed numbers the following year? The first year back in crop was TT canola which appears to have maintained low weed numbers quite well. How will this line look after a second year of crop? Have we achieved enough with a one year break?

Weeds were reduced further after a second year in break crop (Balansa clover), with the same principle, stopping weed seed set using grazing and fodder conservation options. Although there are still weeds present in June after two years of a pasture break, numbers were down to 5 plants per square metre (Figure 1).

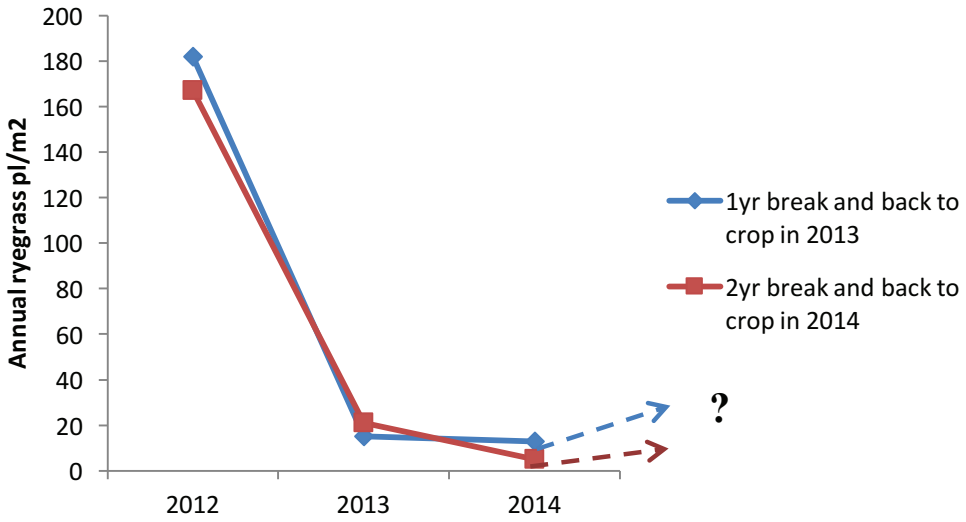

Figure 1. Change in annual ryegrass (ARG) numbers (measured in June) using Balansa clover as a break crop for one year and back to crop compared to two years in the pasture break

Deciding on a break crop species
A range of species were tested, with different species having different growth characteristics and management options. Table 2 displays fodder production, end use and impact on ARG numbers at Lake Bolac. General observations are:

- Oats and ryegrass grow rapidly and compete well early in the season as well as providing a lot of dry matter later in the season
- Annual clovers (Persian, Arrowleaf, Balansa) have been slow to start but bulk up very quickly in spring to provide late competition and high amounts of dry matter
- Lucerne and sub clover were slow and produced little in the first year but came back in the second and third year very quickly and provided great competition throughout the season
- Sowing nothing and allowing weeds to grow (but managed through the season so no seed set) was included, as a low cost option that still produced feed and allowed weed control that wouldn't normally be available in a cash crop.

Different fodder species also allow different options for chemical weed control in-crop so a pasture species can be chosen not just on the basis of its competitiveness, biomass production or potential for N fixation, but also on the chemistry it offers. Rotating herbicide groups and modes of action is a critical part of any IWM strategy.

Table 2. Dry matter production from different species and change in annual ryegrass (ARG) numbers at Lake Bolac 2012-2014 (weeds measured in June)

Species	Dry matter 2012 (kg/ha)	Fodder removal	Change in ARG numbers after 1 year fodder break	Dry matter 2013 (kg/ha)	Fodder removal	Change in ARG numbers after 2 year fodder break
Annual clover[1]	5027	Silage	-87%	5026	Graze, silage	-92%
Sub clover	2416	Graze	-89%	2463	Silage	-93%
Lucerne	1794	Graze	-88%	3035	Graze, silage	-90%
Peas	5434	Hay	-84%	6913	Hay	-96%
Oats	6110	Silage	-87%	10372	Graze, silage	-93%
Ryegrass	5272	Silage	-89%	7753	Silage, graze	-83%
Nothing sown	3138	Graze	-78%	4625	Graze	-91%

[1]Species included Arrowleaf, Balansa and Persian clover

Adding value through break crops

Moving away from continuous cropping does not have to mean sacrificing production or income from that paddock. Utilising a pasture or fodder in the short term can help solve problems in a cropping system (weeds or poor soil structure), provide an opportunity (grazing, fodder conservation or fixed nitrogen) with a vast range of options to cater for the preference of the farmer. There are many mixed farming operations with weed problems and livestock to feed, yet are seeking the ideal break crop in the form of a harvestable grain. Why not grow fodder as the break crop? Project work in 2015 will focus on completion of field trials (4 years of data collection on soil parameters, weeds and yield (DM and grain), as well as factoring in feed values, costs and gross margin to complete the picture.

Take home messages

- Rotations are complex and depend on preference, the problem and opportunities- there is no 'right way'
- The break species can be selected for multiple benefits including grazing value, fodder conservation, nitrogen fixation and improving soil conditions
- If weeds are the problem, focus on targeting the weeds that come late in the season, these are the ones getting through in a continuous crop rotation
- Annual ryegrass can be reduced by up to 90% in two years by stopping weed seed set through fodder removal, whilst providing ample fodder.

Acknowledgements

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Farm level considerations of sowing date for canola and wheat

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Abstract
Sowing date is critical in determining the yield potential and production risk (frost and heat shock) of an individual paddock. Multiple paddocks are sown in sequence each year with sowing date decisions made at the paddock level, but also within the context of a whole farm. Sequential sowing dates were demonstrated in this trial to raise awareness about the different sowing programs that might be employed on a farm. The trial was established (2014) at Cunderdin at the site which hosted the WANTFA Spring Field Day. Wheat (Mace @ 60kg/ha) and canola (IH30RR @ 3kg/ha) crops were sown at approximately 3 day intervals beginning on 29 April and finishing on 1 July (total 24 sowing dates). The trial, visited in spring by farmers and industry professionals, was a backdrop to discuss the risks and benefits of early sowing on yield and flowering date of a cropping program. The maximum canola yield of 1.21 t/ha decreased by 0.17 t/ha for each 10 day sowing delay. However, wheat yield was constant (2.9 t/ha) between 29 April and 1 June, decreasing thereafter by 0.56 t/ha for each 10 day sowing delay. These results demonstrate the importance of early sowing particularly for Canola. The flowering date for each time of sowing was also monitored, with the data used to discuss the spread of flowering across a cropping program, and the implications for frost and heat damage.

Key words
Flowering date, frost, time of sowing, yield

Introduction

In a Mediterranean environment, such as the WA wheatbelt, timeliness of sowing is one of the most important aspects of crop agronomy (Sharma et al. 2008, Turner 2011). There has been a multitude of research examining the effect of sowing date on crop yield and the optimum crop phenology to match this (e.g. Shackley and Anderson 1995, Sharma et al. 2008). There is widespread agreement that the sowing date needs to be managed so there is sufficient time for the crop to complete grain filling before the onset of terminal drought and high temperatures (Turner and Asseng 2005). However, if crops are sown too early then they may be exposed to damaging frosts around anthesis and they may complete grain filling before all of the available soil moisture is utilized, thus yield is less than potential. Whilst the agronomic understanding is well advanced, the reality is that farmers managing a sowing program over many hectares cannot sow all of their crops at the optimum time.

As cropping farms have increased in size and the time taken to complete sowing has increased it has become important for farmers to take a more holistic view. At a farm level sowing time will ultimately be a compromise between some crops being sown early and some sown after the optimum sowing date. For example, Fletcher et al. (2015) showed that early seeding (achieved through dry seeding) gave yield benefits up to 0.5 t/ha across a whole farm but this depended on the number of days taken to sow the cropping program and the growing season rainfall. The objectives of this paper are to establish the farm level yield benefits that accrue from early sowing and investigate the frost and heat stress risks that are associated with sowing time at the farm level.

Materials and methods

In 2014, an unreplicated trial with 24 discrete sowing dates was established at the WANTFA spring field day site near Cunderdin in WA (31.59°S, 117.24°E). Sowings were made at approximately 3 day intervals from 29 April to 1 July 2014. On each date a plot of wheat (cv 'Mace') was sown at 60 kg seed/ha and a plot of Canola (cv 'IH30RR) was sown at 3 kg seed/ha. Fertiliser of 100 kg/ha of Agras (16% N, 9%P, 14% S) was applied at sowing and weeds were controlled by pre-emergent applications of glyphosate. The canola plots received two post-emergent treatments of glyphosate. The ultimate objective of this trial was to provide a backdrop for a field day discussion about farm level sowing dates.

Plots were machine harvested on 18 December and the yields were analysed using regression analysis. Due to the trial being unreplicated, a statistically different yield between any two sowing dates was unable to be established. However, because the trial had multiple sowing dates it was possible to establish, with some certainty, the shape of the yield response with respect to sowing date using a regression analysis. The yield response functions were used to calculate the implications at a farm level of various start dates for a sowing program.

Wheat flowering was monitored on five occasions using digital photography. On each date high resolution digital photos were taken of each plot. From these we identified the plot that had just anthesed. Thus, there were five sowing dates where the anthesis date was known.

Results and discussion

The break of the season occurred on 27 April (49mm) and there was continuing rainfall throughout May (65 mm) and June (27 mm) which ensured that all sowings were made into moist soil and germinated immediately. The overall growing season rainfall (Apr-Oct) was 320 mm. The yield response to sowing date differed markedly between wheat and canola (Figure 1). Wheat yield remained stable at 2.9 t/ha for sowing dates between 29 Apr and 1 June, possibly due to limiting soil N. Thereafter yield declined by 0.56 t/ha for each 10 day delay in sowing ($R^2 = 0.85$). In contrast Canola yield decreased by 0.17 t/ha ($R^2 = 0.55$) for each 10 day delay in sowing from a maximum of 1.21 t/ha at the first sowing date (29 Apr). Canola yields were lower than expected from the early sowings due to shattering losses before harvest.

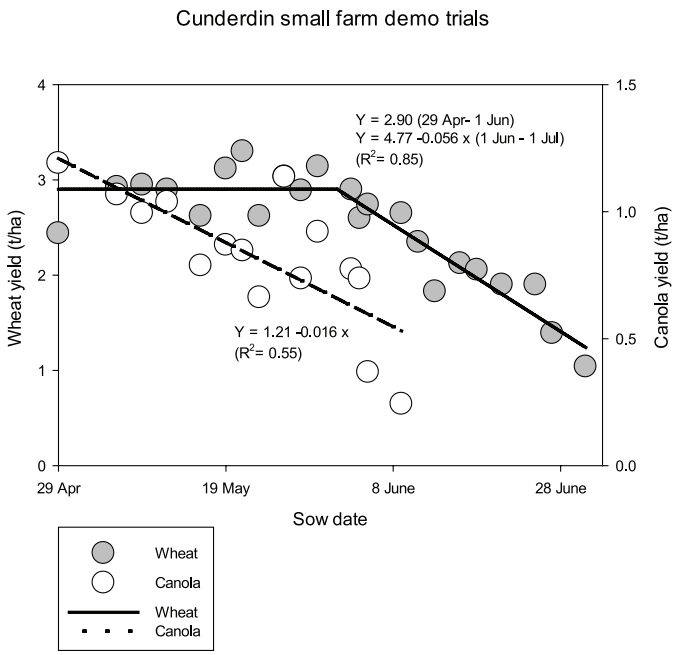

Figure 1. Yield response of wheat and canola to sowing date on at Cunderdin in 2014.

From these responses it would seem that canola should be sown as early as possible and wheat should be sown sometime before the end of June. This would be the case if sowing only took a few days. Using the yield response regressions we were able to calculate the implications at a farm level of various start dates for a sowing program. We use the example of a sowing program consisting of 20% canola and 80% wheat (Table 1). For a short sowing program (20 days) the commencement of sowing can be delayed until 20 May with no major loss in wheat yield and only a small decrease in canola yield. In contrast in a longer program (40 days) any delay of sowing after 30 April resulted in a major decrease in average wheat yield. Thus, the optimum starting date will depend on the amount of sowing that needs to be done and the capacity of machinery available to complete it.

Table 1. Calculated average canola and wheat yields for sowing programs of different duration beginning on different dates.

	20 days			30 days			40 days		
Start date	Canola (t/ha)	Wheat (t/ha)	End date	Canola (t/ha)	Wheat (t/ha)	End date	Canola (t/ha)	Wheat (t/ha)	End date
30 Apr	1.17	2.90	20 May	1.15	2.90	30 May	1.14	2.86	9 Jun
10 May	1.01	2.90	30 May	0.99	2.84	9 Jun	0.98	2.64	19 Jun
20 May	0.85	2.81	9 Jun	0.83	2.56	19 Jun	0.82	2.26	29 Jun
30 May	0.69	2.39	19 Jun	0.67	2.05	29 Jun	0.66	1.72	9 Jul
9 Jun	0.53	1.83	29 Jun	0.51	1.49	9 Jul	0.50	1.16	19 Jul

As expected, where the sowing date of wheat was delayed the anthesis date was also delayed (Figure 1). For every 10 day delay in sowing wheat anthesis was delayed by 8.8 days ($R^2 = 0.97$). The observed flowering dates were well simulated by the Flower Power statistical model (Sharma and D'Antuono 2011). The approximate optimum flowering window is between 25 Aug and 15 Sep in this location (Shackley 2000). This is the window that optimises yield but also balances the risk of frost and heat stress events. Crops flowering before this are considered to be at risk of a frost and crops flowering after this are considered to be at risk of heat stress and terminal drought. In this experiment in order to flower within this window this variety needed to be sown between 14 May and 17 June (Figure 2).

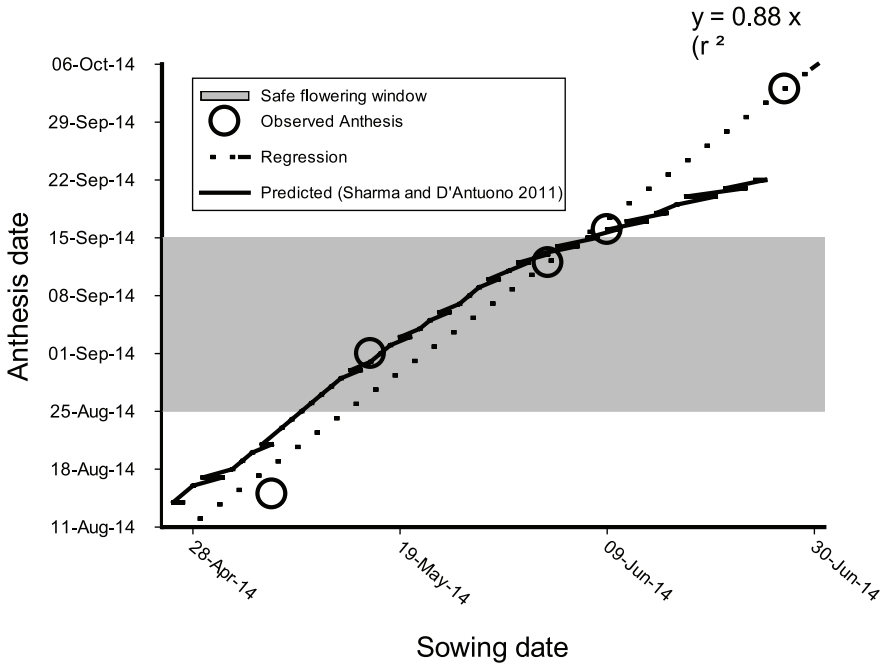

Figure 2. Effect of wheat sowing date on observed anthesis date. The grey area represents the optimum flowering window for Cunderdin (25 Aug to 15 Sep). The dotted line is the regression and the solid line is the predicted flowering dates (Sharma and D'Antuono 2011).

Using the regression in Figure 2 wheat flowering date predictions were made for the same hypothetical cropping program described in Table 1 (Table 2). This showed that when using one variety it was difficult to get all wheat crops flowering within this window particularly for the long program (40 days). In this scenario even if the sowing program commenced on 30 Apr the last wheat crops would flower just outside this window. In contrast sowing of the 20 day program could be delayed by 20 days and still have all wheat flowering just within this window. As the size of the cropping program increases the imperative to begin sowing early is greater.

There is the opportunity to manipulate anthesis date using variety maturity in conjunction with sowing date. For example, flowering of early sown crops can be delayed by using longer maturity varieties (Hunt et al. 2012). The objective should be to get a good spread of flowering within this window. Frost and heat stress events can still happen within this window and if flowering is too synchronised this can result in unacceptable risks.

Table 2. Calculated start and end dates of wheat anthesis across a cropping program of different durations starting sowing of different dates.

	20 Days		30 Days		40 Days	
Start date	Start	End	Start	End	Start	End
30 Apr	16 Aug	30 Aug	18 Aug	08 Sep	20 Aug	24 Sep
10 May	25 Aug	08 Sep	27 Aug	17 Sep	29 Aug	03 Oct
20 May	03 Sep	17 Sep	05 Sep	26 Sep	06 Sep	12 Oct
30 May	12 Sep	26 Sep	13 Sep	04 Oct	15 Sep	20 Oct
9 Jun	20 Sep	04 Oct	22 Sep	13 Oct	24 Sep	29 Oct

This trial was visited by approximately 200 farmers and industry professionals on 2 September at the WANTFA spring field day. This was right in the middle of flowering for the experiment. Farmers were able to see crops that had flowered up to a month earlier and those that would flower up to a month later. The trial was a useful backdrop to a discussion on the impacts of sowing date on growth, development and yield across a whole cropping program. Farmers could literally walk through the range of sowing (and flowering dates) that they had across their whole farm in the space of about 50m. This generated lively discussion and ultimately lead to farmers having a greater appreciation of sowing dates across their programs.

Conclusions

Our results are specific to the 2014 season, which was characterised by above average growing season rainfall particularly early in the season (April and May) and there were no major frost events. The yield and flowering date response to sowing date will be different in each season depending on temperature and rainfall. Furthermore, other seasons are likely to have different frost and heat stress patterns. Therefore, this type of research needs to be repeated over multiple sites/seasons with different rainfall and temperature profiles. Nevertheless, this simple experiment has shown the importance of early sowing across a whole cropping program and that as the time taken to sow a cropping program increases the need to start sowing early increases.

Acknowledgements

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Response to competition and association with yield of chickpea

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Abstract
Donald's ideotype and empirical evidence in crops including rice, wheat and sunflower indicate high yield is associated with less competitive plants. In this study we investigate the response to competition (RC) of 20 chickpea lines in six environments to determine the associations between yield and competitive ability. RC was calculated as the trait value of border row plants (low competition) divided by the trait value of inner row plants (high competition). We calculated RC for yield and yield components including biomass, pod number, seed size, seed number, seed per pod and the derived traits harvest index and pod wall ratio. There was a negative correlation between yield and RC for all yield components except pod wall ratio, seed size and seeds per pod. The largest RC occurred with seed number and yield, with both trait values increasing an average of 1.5 times in low competition conditions compared to high competition. The largest RC for yield was 1.76 and 1.72 for seed number and the lowest was1.31 for yield and 1.27 for seed number.

Keywords
Competitive ability, yield components, breeding, communal behavior, population dynamics

Introduction
Plant-plant interactions include reciprocal negative interactions between neighbours arising from utilisation of a common resource or through interference that is not mediated by resources (e.g. light signals, allelopathy). Donald (1981) originally suggested breeding targeting the 'communal ideotype' which is based on the idea that introgressing traits that confer adaptation to monocultures (weak competitive ability) will result in higher yield. The communal ideotype has been documented in cereals (Jennings and Jesus, 1968, Hamblin and Donald, 1974, Reynolds et al., 1994, Romani et al., 1993, Thomas and Schaalje, 1997) and sunflower (Sadras et al., 2000). A secondary consequence of competition is the impact on yield and performance at the plant and plot level. Failure to recognise this impact may introduce confounded effects into trials which in turn may lead to identification of germplasm of limited value (Rebetzke et al., 2014).

Currently there is no information on the relationship between intraspecific competitive ability and yield for chickpea, or the underlying physiological determinants of this relationship. Understanding more about chickpea communal behaviour will enhance our understanding of chickpea physiology and the underpinnings of yield within chickpea production systems.

Methods
Plant material, environments and experimental design
A selection of 20 chickpea lines were chosen in consultation with the Australian national chickpea breeder (Dr Kristy Hobson), representing a broad range in adaptation and key traits. The lines varied in yield, phenology, disease resistance and seed type (kabuli or desi). Accessions were compared in six environments in South Australia that were a combination of locations, seasons and sowing dates. The six environments were Turretfield (34°33'S, 138°49'E) at recommended sowing time (TOS 1; 8th June 2013 and 6th June 2014) and late sowing time (TOS 2; 9th of July 2013 and 15th of July 2014), and Roseworthy (34°52'S, 138°69'E) at recommended sowing time (TOS 1 on 10th June 2014) and late sowing time (TOS 2 on 15th July 2014). Experimental plots were sown in a randomised complete block design with three replicates. Plot size was 7.25m2, comprised of six rows (spaced 23cm) of five meters length. Plots were spaced 55cm apart from each other (rather than the usual 30cm) for decreased competitive pressure in border rows (Rebetzke et al., 2014). The target plant density was 50 plants m-2. Diseases were controlled with preventive treatments.

Measurements
Phenology was scored on a weekly basis with stages recorded when reached by fifty percent of plants in a plot. Stages scored included the time to: flowering, pod emergence, end of flowering and maturity (yellowing

pods). Phenology was expressed on a thermal time scale, calculated from daily mean temperature and base temperature of 0ºC. Yield and components were measured from two 50cm cuts taken from either border (low competition) or inner rows (normal competition). Yield and components were measured from outer rows and their associated RC expressed as a ratio of the control yield and components (Reynolds et al., 1994, Sadras et al., 2000). Yield components measured included biomass, seed weight, seed number, pod number, seed size, seeds per pod and the derived traits harvest index (seed yield/shoot biomass) and pod wall ratio (pod wall weight/whole pod weight).

Results

Yield

Across all environments and varieties, yield ranged from 138 g m-2 to 627 g m-2. The highest average yield for an environment was 390 g m-2 and the lowest average was 292 g m-2. The lowest average yielding line yielded 278 g m-2 with a range of 192 – 392 g m-2 and the highest average yielding line yielded 392 g m-2 with a range of 226 – 627 g m-2.

Phenology

The range of time to flowering was 946ºCd for Sonali up to 1224ºCd for Genesis Kalkee. Time to pod emergence ranged from 1110ºCd for Sonali to 1325ºCd for Genesis Kalkee, and end of flowering ranged from 1356ºCd for PBA Striker to 1510ºCd for Genesis Kalkee. The environment with the shortest season was Roseworthy late sown (2014), with 874ºCd to flowering, 979ºCd to pod emergence and 1233ºCd to end of flowering. The longest season was Turretfield normal sowing (2013), which had 1235ºCd to flowering, 1422ºCd to pod emergence and 1625ºCd to end of flowering. There was a positive relationship between yield and time to phenological stage, with the most significant relationship being between yield and maturity (r2 = 0.36, P = <0.0001).

Response to competition

The range for yield response to competition across environments was 1.40 to 1.87. The range between varieties was 1.31 to 1.76. A larger response to competition was associated with lower yield (Figure 1). Yield had a significant negative correlation with response to competition of yield, biomass, pod number, harvest index, seed number and seed per pod (Table 1). The relationship between yield and response to competition varied with sowing date as reflected in positive residuals for early and negative residuals for late sown crops (Figure 2). Time to maturity accounted for a significant part of the scatter in the relationship of yield and response to competition (Figure 3).

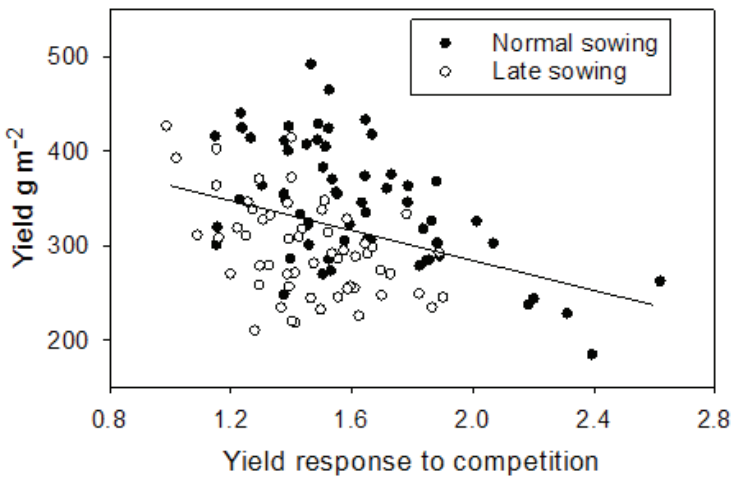

Figure 1: Effect of RC on yield. Data are based on the 20 lines and 6 environments. Data points are average of three replicates. Closed symbols are from normal sowing and open symbols are from late sowing. R^2 = 0.12 and *P* <0.0001.

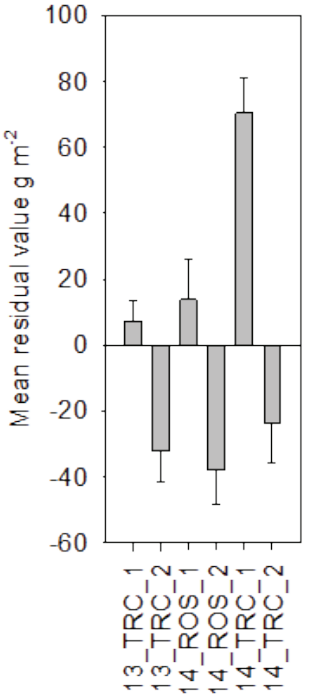

Figure 2: Average residual of the relationship between yield and response to competition (Fig. 1) for each environment. Abbreviations: 13 and 14 denote year, TRC = Turretfield, ROS = Roseworthy, 1 = normal sowing and 2 denotes late sowing. Error bars are one standard error. Differences between environments were significant (P <0.001).

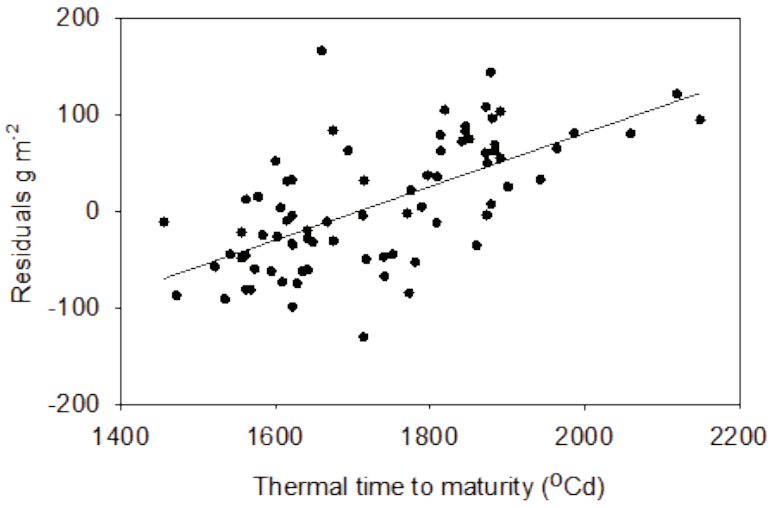

Figure 3: Residuals of the relationship between yield and response to competition (Figure 1) against thermal time from sowing to maturity. R2 = 0.41 and P <0.0001.

Table 1: Correlation matrix of response to competition (RC) for different traits and crop yield (measured in the inner row - normal competition). Significance is indicated as **P<0.0001 and P<0.05 according to Fischer's r to Z test.

	Response to competition **(RC)**							
	Pods	Yield	Seed size	Harvest index	Pod wall ratio	Seeds	Seed per pod	Yield (inner row)
Biomass (RC)	0.83**		0.23**	0.28**	-0.02		0.10	-0.41**
Pods (RC)			0.13*	0.44**	0.08		-0.26**	-0.42**
Yield (RC)			0.25**	0.60**	-0.10		0.19*	-0.45**
Seed size (RC)				0.18*	-0.05	-0.02	-0.26**	0.06
Harvest index (RC)					-0.21**		0.27**	-0.31**
Pod wall ratio (RC)						-0.09	-0.30**	-0.03
Seeds (RC)							0.27**	-0.47**
Seed per pod (RC)								-0.14*

Discussion

Previous studies in cereals and sunflower have confirmed the theory of "Donald's ideotype" with more competitive lines producing a lower yield in pure stands. This is the first study that investigates grain legumes. Our finding conforms to theory: lines that are more responsive to competition have a lower yield than their less responsive counterparts. Sadras et al. (2000) reported a yield response to competition of 0 to 84% in sunflower, while Reynolds reported differences of 25 to 40% in wheat, which compares with our observations of 31 to 76%. The responses to competition and associations with yield varied among environments and phenology. For the same response to competition, yield was higher in normal sowing environments and for lines with longer season. Although we had a significant effect of response to competition on yield, there was little difference between the response of varieties to competition, a result also reported by Romani et al. (1993).

Conclusions

This research has demonstrated that a less competitive chickpea phenotype is associated with higher yields and conforms to the idea of the 'communal ideotype'. It has also highlighted the potential risks of selection based on single plant performance or mass selection of highly competitive phenotypes as selection for yield will favour competitive phenotypes.

Acknowledgements

GRDC funds our research in pulses. We also thank the Australia–India Strategic Research Fund for financial support. We thank Michael Lines, Stuart Sheriff, Kathy Fischer and John Nairn for the establishment and maintenance of crops, Dr Kristy Hobson for sharing knowledge and her assistance with germplasm. This paper will form part of Lachlan Lakes PhD thesis and is intended for publication in a peer reviewed journal.

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Change in biomass partitioning and transpiration efficiency in Australian wheat varieties over the last decades

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Abstract

Wheat productivity is commonly limited by a lack of water in rain-fed farming systems. Increasing transpiration efficiency, by increasing plant biomass produced per unit of available soil water, can lead to gains in crop yield. Although Australian wheat breeders have historically bred for increased yield, grain quality and disease resistance, other traits are expected to have been indirectly selected for. A set of 15 elite wheat varieties with wide adoption and narrow phenological range was chosen to study breeding progress achieved in Australia between 1973 and 2012. Performed in irrigated pots at normal field density, this study revealed changes in transpiration efficiency, biomass partitioning and senescence rate in varieties released over the last four decades. While plant biomass did not change significantly across cultivars, differences in partitioning were observed, with modern cultivars having greater biomass allocation to the stems and spikes, but reduced allocation to the leaves. Modern cultivars had a greater number of fertile tillers, less infertile tillers and less senesced leaves at flowering. Interestingly, a significant increase in whole-plant transpiration efficiency was observed with the year of cultivar release, giving promising results for future wheat improvement. Further study is needed to unravel the underlying physiological and genetic processes associated with increased transpiration efficiency and generate wheat lines that produce more 'crop per drop'.

Key words

Water-use, tillering, spike, stem, breeding.

Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most significant staple crops. In Australia, wheat is mainly grown under rain-fed conditions and experiences major water stress that limits productivity (e.g. Chenu et al 2013). Although physiological responses to water deficit are complex, it is likely that traits associated with drought tolerance have been indirectly selected through conventional breeding programs in drought-prone areas. In a collection of Australian wheats released between 1958 and 2007, significant increase in yield over the year of release have been related to (i) a decrease in grain protein content and to (ii) an increase in pre-flowering radiation use efficiency, leaf greenness at flowering and nitrogen uptake, while (iii) no change in evapotranspiration, flag leaf stomata density, light-saturated photosynthesis and respiration was observed (Sadras et al., 2012; Sadras and Lawson, 2013). Looking at Australian cultivars released between 1973 and 2012, this project is investigating traits related to biomass partitioning and transpiration efficiency to determine other possible changes that may have resulted from the last few decades of breeding.

Material and methods

Trial description

Fifteen elite Australian wheat varieties with wide adoption and narrow phenological range were chosen to represent breeding progress achieved in Australia between 1973 and 2012 (Fig. 1). Plants were sown in pots at a density of 100 plant m^{-2} (i.e. two plants per pot) in a greenhouse at Gatton (-27.55°, 152.34°), in a row-column design with 5 repetitions (i.e. 10 plants) per variety. Plants were grown in the 'Pot in Bucket' (PIB) system adapted from Hunter et al. (2012), and had a continuous supply of water from independent water jugs, which allowed transpiration to be measured by the amount of water removed from each jug. A layer of white plastic beads was applied to cover the soil in each pot and avoid soil evaporation. A set of five pots with no plant was used to calculate remaining soil evaporation throughout the trial.

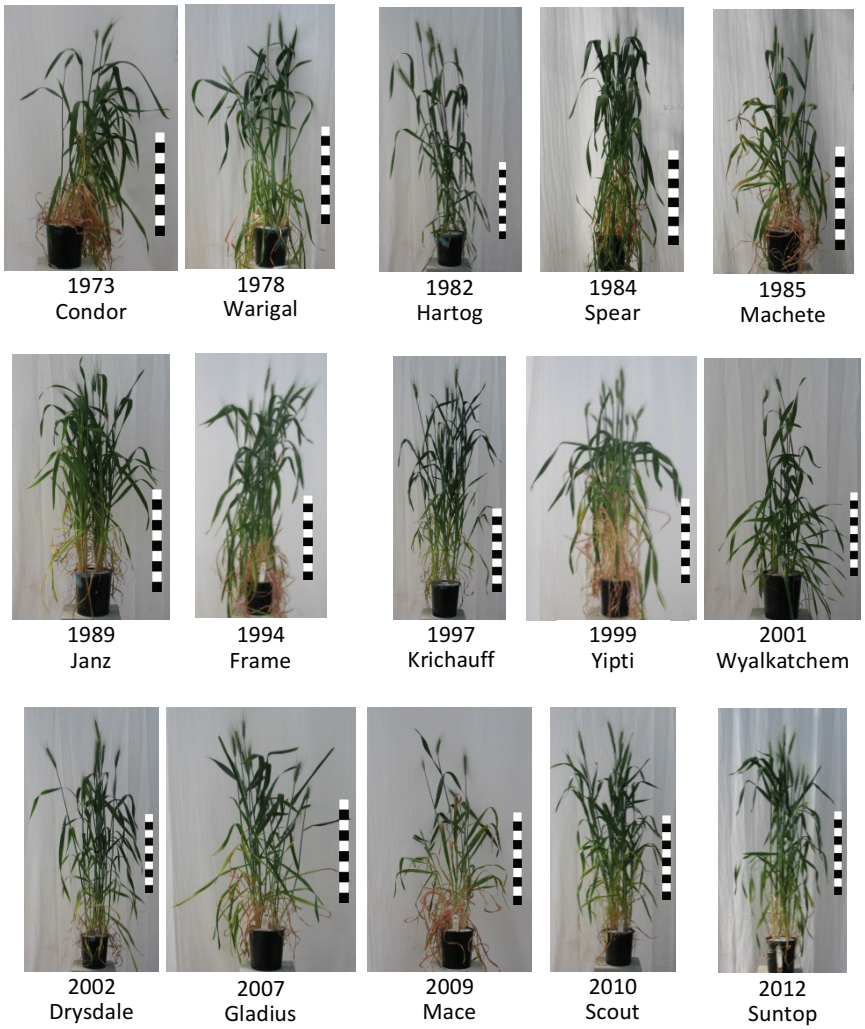

Figure 1 - Studied elite Australian wheat varieties with their year of release. The black and white scale corresponds to 45 cm.

Measurements and analysis

Transpiration was recorded weekly for each pot from 25 days after sowing until flowering. Zadoks scores (Zadoks et al., 1974) were recorded weekly for the main stem of one plant in each pot as a measure of phenological development. Each pot was harvested when at least 50% of the stems had reached flowering, i.e. at a Zadoks score of 65 or higher. Both plants in each pot had their total leaf area, number of fertile and infertile tillers, and dry biomass of roots, stems, dead and green leaves and heads measured at flowering. Transpiration efficiency was calculated as the ratio between either whole-plant dry biomass or shoot dry biomass at flowering over the amount of water transpired from 25 days after sowing till flowering. Cumulated transpiration was defined as the total water use minus the average cumulated soil evaporation measured in five pots with no plant. All data analysis was done using the R statistical language (R Core Team, 2014).

Results and Discussion

No trend in plant biomass, but biomass partitioning changed with the year of variety release

No significant trend in plant biomass was observed for varieties released between 1973 and 2012 (Fig. 2a) but differences were recorded in the partitioning of plant biomass (Fig. 2b-f). Significant differences were only observed in the partitioning among above-ground organs, as neither partitioning to the shoot, nor to root significantly changed with the year of release. Modern varieties had less biomass partitioned to the leaves, to the benefit of the stems and heads. Interestingly, changes observed for leaves arose from a decrease in dead leaves, while green-leaf biomass at flowering did not significantly change over the last decades. Hence, breeders seem to have indirectly selected for lines with reduced pre-flowering senescence, which invest an increasing amount of resources towards reserve and reproductive organs.

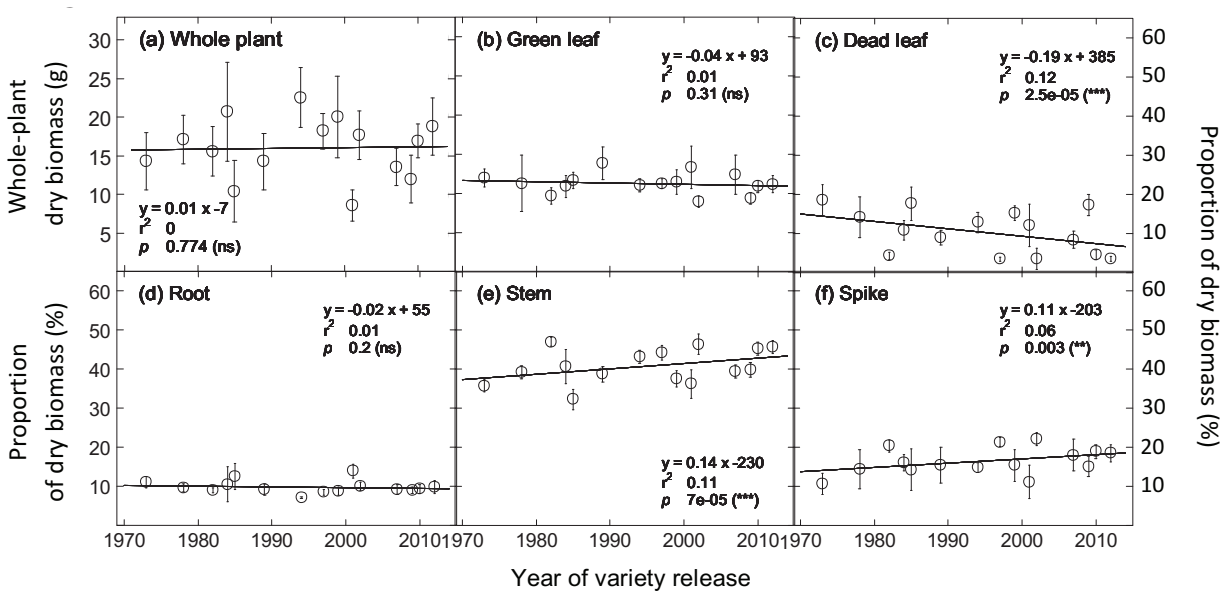

Figure 2 - Change in biomass over year of variety release for (a) whole-plant dry biomass, and the portion of dry biomass allocated to (b) green leaves, (c) dead leaves, (d) roots, (e) stems, and (f) spikes. Error bars correspond to 95% confidence interval (n = 5-10). Linear regressions were calculated on row data (individual pots for root biomass or individual plants for all other traits). Abbreviations: ns, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

Since the 1970's, for the genotypes studied, the proportion of biomass allocated to the stems and the spikes has increased by +0.14% and +0.11% per year, respectively, meaning an average increase of +10% for stems plus spikes in four decades. Interestingly, the most noticeable effect was for the spikes, which increased from 13 to 18% of the plant biomass, over the last four decades (Fig. 2f). For comparison, the stem portion increased from 37% to 42% during the same period (Fig 2e).

Such change in partitioning can be at least partly explained by the change observed in tiller number (Fig. 3a). While the number of total tillers has slightly but significantly decreased since 1970's (from 10.3 to 8.8 between 1970 and 2010), the number of fertile tillers (Fig. 3b) has substantially increased (from 5.5 to 7.0). Accordingly, the number of infertile tillers has drastically decreased, with the most modern varieties having almost no infertile tiller (Fig. 3c).

Overall, the changes observed in tillering, senescence and biomass partitioning reflect that modern varieties (i) invest less resources in plant structure that die relatively early during the crop cycle, (ii) accumulate more biomass in reproductive organs (spike) and in reserve organs (stems), which can benefit yield under late drought conditions (Dreccer et al., 2009) that are frequently occurring in Australia (Chenu et al., 2011 and 2013).

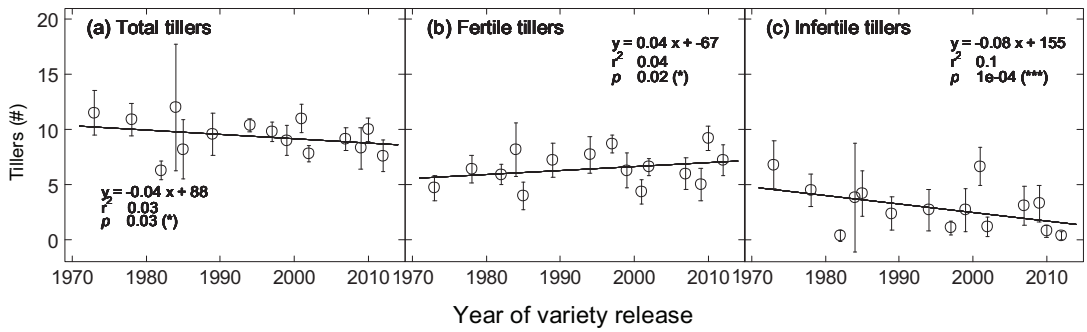

Figure 3 - Change in (a) tiller number, (b) fertile tillers, and (c) infertile tillers over year of release. Error bars correspond to 95% confidence interval (n = 10). Linear regressions were calculated on row data (individual plants). Abbreviations: ns, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

Transpiration efficiency increased over the last decades

While modern cultivars seem more efficient in partitioning their resources towards reproductive organs, they were also found to be more efficient in converting transpired water into biomass (Fig. 4). Plant transpiration

efficiency, whether it was calculated for above-ground biomass (Fig. 4a) or for the whole plant (Fig. 4b), has increased significantly with the year of release. Such increase resulted from a slight increase (not significant) in biomass (Fig. 2a) and a slight decrease (not significant) in cumulated transpiration (data not shown).

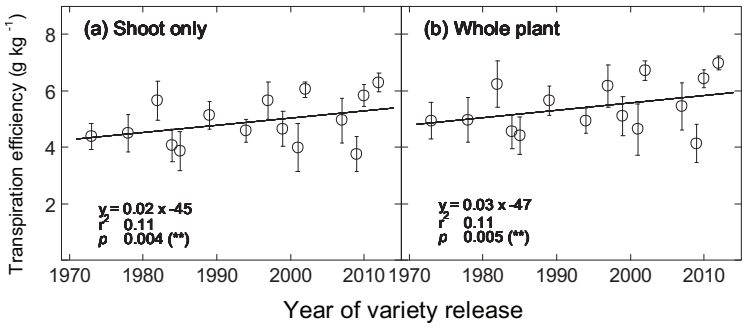

Figure 4 - Change in transpiration efficiency for (a) above-ground dry biomass and (b) whole-plant dry biomass for varieties released between 1973 and 2012. Error bars correspond to 95% confidence interval (n = 10). Linear regressions were calculated on row data (individual plants). Abbreviations: ns, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

Conclusion

This study focused on Australian wheat lines that breeders have selected under rain-fed conditions. While conducted in well-watered conditions, substantial changes were identified in traits likely to be beneficial under drought. A significant trend in increasing number of fertile tillers was observed with the year of release, while the number of total tillers significantly decreased. Modern cultivars had less infertile tillers, less early senescence, but maintained a similar plant leaf area and green-leaf biomass as old varieties at flowering. In this small-pot experiment, no trend in root biomass or in shoot:root ratio was observed over the year of variety release. Interestingly, a significant increase in transpiration efficiency was observed for modern varieties. Further study is needed to confirm those results, to assess existing variability in promising traits that could further be improved such as transpiration efficiency, and to unravel associated physiological and genetic processes to assist breeding for lines that produce more 'crop per drop'.

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Year of variety release

Yield components of reduced tillering wheat lines from the Yaruna multi-parent population

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Abstract
Reversing the trend of declining rates of wheat yield increase in Australia will require a substantial change in the genetic and management bases of production. Key genetic attributes may include reduced tillering and improved grain number/ear. In this paper yield components of plants from a bulk population of wheat (Yaruna multi-parent population = YaMPP) containing homozygous reduced tillering genotypes derived from a diverse 9 parent cross which included the very reduced tillering Uniculm 492 line are described. Yield components of main culms of individual homozygous plants grown in field plots at 100-150 plants/m^2 are often 1.2 to4 times greater than free tillering varieties. Selected lines exhibiting the 'tin' gene when grown at standard crop densities have achieved HI values greater than 0.5, and grain numbers/ear over 60 and as high as 146. Many individual plants in YaMPP and the selected lines exhibit reduced tillering, large grain numbers per ear, large and often uniform grain size, very strong straw, and plant height between 60 and 100cm. Improvements in these components are necessary to increase yields in the dryland systems found in Australia, and a key challenge is to test the yield potentials of a broader range of reduced tillering genotypes under a diversity of environments.

Key words
Uniculm, ideotype, yield components, reduced tillering, 'tin'

Introduction

The reduction in rates of yield improvement in wheat in Australia have been characterised by a number of authors (eg. Lake, 2012; Fisher et al., 2012). Zhang et al, (2012) have indicated a strong need for either increased harvest index or increased grain number/m^2 as ways to increase yield in the high rainfall zone of Western Australia. However in dry seasons the high tillering of modern varieties which drives grain number/m^2 can impose a significant cost in wasted water use before grain filling starts. Reduced tillering lines in theory provide opportunities to use water more efficiently and so increase yield under terminal drought stress. In practice '*tin*' genotypes have often not achieved this, and instead shown equal or reduced yield (Mitchell, et.al, 2012). In this paper I provide results for plants containing the *tin*" gene, developed in a segregating population using the 'B' model selection ideotype of Donald and Hamblin (1976), which may be useful as a source of genetic variability to increase yield components in dryland wheat.

Materials and Methods

The Yaruna Multi-Parent Population (YaMPP) was derived from a complex cross between 9 parents involving Miling, Egret, Gabo, Pitic 62 (occurs twice), Mexico 120, Ramona and Stewart (durum), with the final cross made in 1987 to Uniculm 492 (Atsom and Jacobs, 1977; Richards, 1988). The segregating population has been grown as a bulk in the medium rainfall wheat belt of Western Australia since 1993. In 2003 approximately 300 primary ears were selected at maturity from plants exhibiting uniculm, biculm or triculm character as the sole determinant for selection. The seeds were bulked and continue to be grown and harvested as the primary YaMPP. In each year a compound starter fertiliser with nitrogen between 6 and 10kg/ha and phosphorus between 3 and 10 kg/ha is applied in the seeding operation.

Two assessments were made of the genetic material in 2014 – firstly of plants from the YaMPP bulk, and secondly of lines derived from single ear selections from YaMPP taken in 2012. Small plots were grown on a medium fertility red loam with a weak hardpan at about 40cm, and sown at a seed rate of 70kg/ha with a compound fertiliser that delivered 6kg/ha of nitrogen and 5kg/ha of phosphorus. The plots were sown in mid-June, harvested during December and January, and received 320mm growing season (April to October) rainfall. Final plant density ranged between 100 and 150 plants/m^2.

In the first assessment, three 2.5 metre lengths of row from the centre of a 5 row YaMPP plot were sampled. Individual culms exhibiting the largest ear size (main stem) from each of 17 plants/replicate were harvested, oven dried and measured for plant height, non-ear culm weight (SW), grain weight/ear (TGW), spikelet number/ear (SN) and grain number/ear (GN). The 1000 grain weight (1000GW), harvest index/culm (HI = TGW/SW+TGW+ chaff weight) and grain number/spikelet (Gr/Sp) were derived values. The remaining plant material from each replicate was threshed to provide a dry weight of grain. A yield estimate for YaMPP was calculated using the combined data sets from the individual plants and the bulk sample replicates. An additional 49 primary culms collected at random from uniculm, biculm and triculm plants in the centre rows of other YaMPP plots provided a total of 100 ears for the population analysis. The full 100 culms were used in the correlation analysis of yield components.

In the second assessment detailed measurement of yield components was undertaken for the 'tin' line BCW2 (derived from YaMPP), identified as having high yield potential from small plot experiments in 2013. Six uniculm, biculm, and triculm plants, and six plants with apparently higher stem number (4-5) were sampled and data from all culms collected (the higher stem number plants were found to be multiple seeds at a single point – data not presented). As a standard, 10 culms from plants of Magenta wheat grown at the same site and under similar conditions, and 10 culms from plants of Mace wheat from an adjacent commercial crop were analysed.

Four '*tin*' lines selected from YaMPP in 2012, but which exhibited lower yields than BCW2 in small plots in 2013, were also grown in small field plots and some yield components measured. With the lines BCW3, BCW5, BCW6 and BCW7 eighteen culms were sampled.

Results

The YaMPP single culm selections are characterised by a diverse, but normally distributed range of yield component characteristics, many of which are strongly related to grain yield per ear (Table 1). Harvest index/culm is high in a number of selected plants (eg, plant 5, 55), but this is not necessarily associated with increases in other yield components. Some individual plants (Table 1) and the selected lines BCW2-7 show culm yield components much greater than conventional varieties (Table 2), and with values 1.2 to 4 times greater. There are strong positive correlations of spikelet number per ear, stem weight, 1000 grain weight, grains/spikelet and grains/ear to total grain weight/ear. Harvest index was negatively correlated with stem weight in this population and positively correlated with 1000 grain weight.

Table 1. Yield components of the main stem of 100 plants sampled from the YaMPP in 2014, of 7 *'tin'* plants with the highest yield individual components (highlighted in bold), and the Yield Component (YC) correlations of the 100 plants.

	Plant Height (cm)	SpN	SW (g/stem)	TGW (g/ear)	1000 GW (g/1000)	HI	GN	Gr/Sp
Popn Mean	75	20.30	3.84	3.45	44.4	0.47	78	3.8
Max.	110	30.00	8.29	6.50	57.00	0.58	146.00	5.6
Min.	58	13	1.22	0.38	14.6	0.16	14	0.7
Plant 4	**110**	22	3.52	2.8	42.6	0.44	71	3.2
Plant 24	76	**30**	5.95	5.72	40.4	0.49	**146**	4.9
Plant 43	77	27	**8.29**	6.11	50.6	0.42	129	4.8
Plant 17	87	26	7.32	**6.5**	48.8	0.47	130	5.0
Plant 5	83	21	3.68	5.1	**57**	0.58	91	4.3
Plant 55	77	17	2.36	3.24	50.6	**0.58**	64	3.8
Plant 45	81	21	7.31	5.21	53.8	0.42	117	**5.6**
YC corr.								
PH	-	0.13	0.42	0.41	0.35	-0.04	0.33	0.39
SpN		-	0.61	0.66	0.18	0.08	0.76	0.43
SW			-	0.84	0.48	-0.22	0.84	0.78
TGW				-	0.68	0.27	0.95	0.88
1000GW					-	0.4	0.45	0.52
HI						-	0.2	0.25
GN							-	0.9

For Correlation analysis P<0.05=0.196, P<0.01=0.255

While the plants within YaMPP are now essentially homozygous, the oligoculm BCW2 still showed plasticity for the 'tin' character with uniculm, biculm and triculm plants present in the plots. The individual yield components per culm were largely stable for plants expressing 1, 2 or 3 tillers (Table 2). The five BCW lines also exhibited improved yield component values per culm over the free tillering varieties and similar to the Uniculm 492 parent. When grain from BCW2 was sorted through different sieve sizes 89% of seed was greater than 2.8mm and only 0.1% below 2mm, while the mean value for the YaMPP replicates was 62%. Seed from an adjacent commercial crop of Mace wheat (R and B. Gentle) planted 3 weeks earlier and with higher nitrogen application achieved 30% of seed greater than 2.8mm (paddock yield just over 3t/ha).

Table 2. Yield components of BCW ('*tin*') lines derived from YaMPP and free-tillering WA varieties in 2014 field or farmers plots, and the Uniculm 492 source of reduced tillering germplasm (from literature)

Genetic material	SpN	SW (g/culm)	TGW (g/ear)	1000 GW (g/1000)	HI	GN	Gr/Sp
BCW2 (*tin*)							
- Uniculm plant	20.8	2.8	4	48.5	0.51	84	4
- Biculm plant	19.0	2.3	3.4	47.1	0.52	71	3.7
- Triculm plant	19.9	2.6	3.4	44.7	0.48	76	3.8
BCW3 (*tin*) -		3.0	3.3	51.2	0.53	65	
BCW5 (*tin*)		2.4	3.3	50.8	0.58	64.5	
BCW6 (*tin*)		2.5	3.4	54.0	0.58	64	
BCW7 (*tin*)		1.9	2.9	51.0	0.60	57	
Mace - farmer	13.5	1.3	1.4	40.3	0.46	34	2.5
Magenta	12.9	1.0	1.3	40.0	0.48	33	2.6
Uniculm 492 – from Atsom and Jacobs / *Richards (1977/1988)*	20.8	3.4	4.4	41.4	*0.48*	106, *64-85*	5.1

The YaMPP bulk yield analysis produced a yield of 4.5t/ha compared to the 3.56t/ha site mean at the closest NVT trial site 5 km away (sown 3 weeks earlier on a similar soil type and with 90 kg N/ha applied during the growing season (NVT Trials - WMaA14YORK6).

Observation of the YaMPP over the last 5 years shows that it contains plants with a range of morphological and physiological characteristics. These include, but are not limited to, strong straw, large dark green leaves, reduced tillering, differing ear shape, large grain size, large grain number per ear, flowering time, grain filling efficiency (crease in-fill), grain shape, waxy leaves, and stay green character.

Discussion

The development of YaMPP and the use of the reduced tillering line Uniculm 492 as a parent used a similar, though independent, approach to that reported by Indian plant breeders who have developed similar material – the Indian New Plant Type (Singh et al., 2001) and which has a reported yield increase of 20—30% over free tillering varieties. Australian germplasm with reduced tillering genes has focused on the use of isogenic lines to test hypotheses that reduced tillering has benefits in dryland production systems. Improved grain size and reduced screenings have both been found using this approach (Mitchell, et al 2012). The oligoculm line BCW2 expressed both increased grain weight and very large grains size with very low screenings, despite having nearly 25-30% of its ear weight as chaff, and strongly supports the hypothesis that reduced tillering is an advantage for reducing screenings under at least mild late season water stress.

The diversity of plant types with '*tin*' characteristics present in the YaMPP material offers a new opportunity to explore the physiology of yield in a dryland environment with a short growing season. Many of the components identified as being necessary to lift yield above the current level in the higher rainfall zone (Zhang, et al, 2012) are present in plants from the YaMPP population, with grain number per ear being

particularly high in some ears when grown under commercial field densities. If ear number/ha can be maintained at or above the 250/m^2 target (125 plants/m^2 X mean 2 ears/plant) for these types, then substantial yield improvement would appear possible.

While fully replicated yield tests reduced tillering lines from YaMPP are currently underway, the bulk population yield of YaMPP from 2014 provides limited evidence that yield improvement should be possible. Mitchell et al (2013) found yield increases with reduced tillering lines under mild stress in the order of 11% compared to free tillering lines, although the isogenic lines in their experiments expressed low kernel weights. Using a potential yield estimation formula (Passioura and Angus, 2006) of kernel number/ha X kernel weight for BCW2 for a hypothetical ear number of 250/m^2, produces an estimated potential yield of 8.3t/ha – or a doubling of the best commercial yields reported by farmers in the York area of WA, and twice that from the Mitchell et al. (2013) experiments.

The genotypes with higher yield components which are necessary to increase yields in the dryland systems may include those with reduced tillering. These genotypes exist within Australia and the world, and a challenge is to test the potentials of a broader range of reduced tillering genotypes under a diversity of environments for improved yield and quality.

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Potential role of 3D modelling of canopy architecture to explore G x E x M interactions in wheat

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Abstract
The potential yield of a crop in a specific environment depends on its canopy architecture, which refers to the dynamic changes in size, orientation and spatial arrangement of leaves and other plant organs over time, as driven by the underlying physiology. Canopy architecture is increasingly viewed as a trait to be manipulated by plant breeders as it influences how plants capture resources. However, selection for specific architectural traits has been elusive, partly because architecture is only one of many traits affecting yield and partly because effects of architecture on resource capture are hard to quantify. Advances in modelling of plant architecture and physiological functions using functional-structural plant (FSP) models allow for feedbacks between environmental factors, architecture, and selected physiological processes to be explored. As an example, an FSP model of spring wheat was developed to dynamically simulate the architecture of an expanding wheat crop, taking into account growth and development, size, shape and orientation in space of each organ in relation to thermal time. Here, we show how this model can be used to assess the effects of different planting arrangements (row and grid configurations) on light intercepted by a wheat canopy. We conclude that FSP models could assist in exploring contributions of architectural traits to crop performance to improve understanding of G x E x M interactions.

Introduction
Plant architecture, the three-dimensional organization of the plant body, is a key determinant of light capture in plants. Therefore, architectural traits are interesting targets for breeding. However, effects of architectural traits such as leaf angle and tillering on light capture are difficult to assess. To this end, simulation of plant architecture, termed functional-structural plant (FSP) modelling is a promising tool. FSP modelling is used to simulate "the development over time of the 3D architecture or structure of plants as governed by physiological processes which, in turn, depend on environmental factors" (Vos, Evers *et al*. 2010). A frequently used synonym of FSP modelling is virtual-plant modelling (Room, Hanan *et al*. 1996).

FSP models have a rich history of variation in methods of implementation, in degree of complexity and biological realism, as well as in the associated simulation platforms such as L-Studio (Prusinkiewicz, Karwowski *et al*. 2007), GroIMP (Hemmerling, Kniemeyer *et al*. 2008), and OpenAlea (Pradal, Dufour-Kowalski *et al*. 2008). The common denominator of all FSP modelling approaches is the explicit inclusion of (aspects of) plant architecture, which results from the general philosophy behind FSP modelling that plant architecture is a concept central to plant growth and development. To be able to support research on plant growth and development, FSP modelling has several distinctive properties to offer. Capturing of plant topology, i.e. the structure of the network of interconnected organs, allows simulation of transport of compounds such as assimilates or hormones through the plant from source to sink organs, taking into account the number of nodes to travel and the number of ramifications to encounter. Additionally, the simulation of the (3D) geometry of the plant, its leaves and other organs, and the direct and diffuse light coming from any direction enables the calculation of local and whole-plant light absorption. This is vital for the simulation of photosynthesis and photomorphogenetic processes. Simulation of root system geometry can support studies exploring the uptake of water and nutrients from spatially heterogeneous soils (Dunbabin, Postma *et al*. 2013). Finally, a property of FSP modelling crucial for questions related to plant growth and development in the crop and agricultural sciences is the ability to include external factors such as environmental variables (light, water, nutrients, herbivores, volatiles, *etc*.) and management (plant manipulation, planting pattern or density, biocide spraying, etc.). The purpose of this study was to demonstrate the applicability of FSP modelling to explore the effects of different planting arrangements on light interception in a wheat canopy.

Methods

To demonstrate the capacity of FSP modelling to simulate crop light interception in relation to architecture and planting arrangement, we used an existing simulation model of wheat architecture (Evers, Vos *et al*. 2005; Zhu, Van der Werf *et al*. 2015), implemented in the simulation platform GroIMP (Hemmerling, Kniemeyer *et al*. 2008). The model simulates, on a daily time step, the development of the aboveground parts of the wheat plant in terms of leaf appearance, expansion, and senescence, tiller appearance and senescence, as well as geometrical properties such as leaf angle and curvature. For details see the aforementioned papers. The model was calibrated for the CSIRO wheat line 7770N (genetic background: Australian cultivar Wyalkatchem) grown at a population density of 125 plants m^{-2}, using observations of developmental rate, sizes of individual plant organs, and tillering behaviour as model inputs (Moeller, Evers *et al*. 2014).

Light interception by the canopy was simulated using the GroIMP light model, with direct and diffuse light coming from light sources arranged appropriately (Evers, Vos *et al*. 2010). Simulations of canopy light interception were done for three contrasting planting arrangements: 20 cm row spacing, 30 cm row spacing, and a regular, square grid configuration with 9 cm distance between individual plants, all at a plant population density of 125 plants m^{-2}. The expansion of organs was entirely based on empirical rules, hence the same for each canopy configuration, and the light intercepted was not used to drive growth. To eliminate border effects on light interception, only the central area of the virtual plots was used for the calculation of canopy light interception. Figure 1 illustrates the visual output of the model.

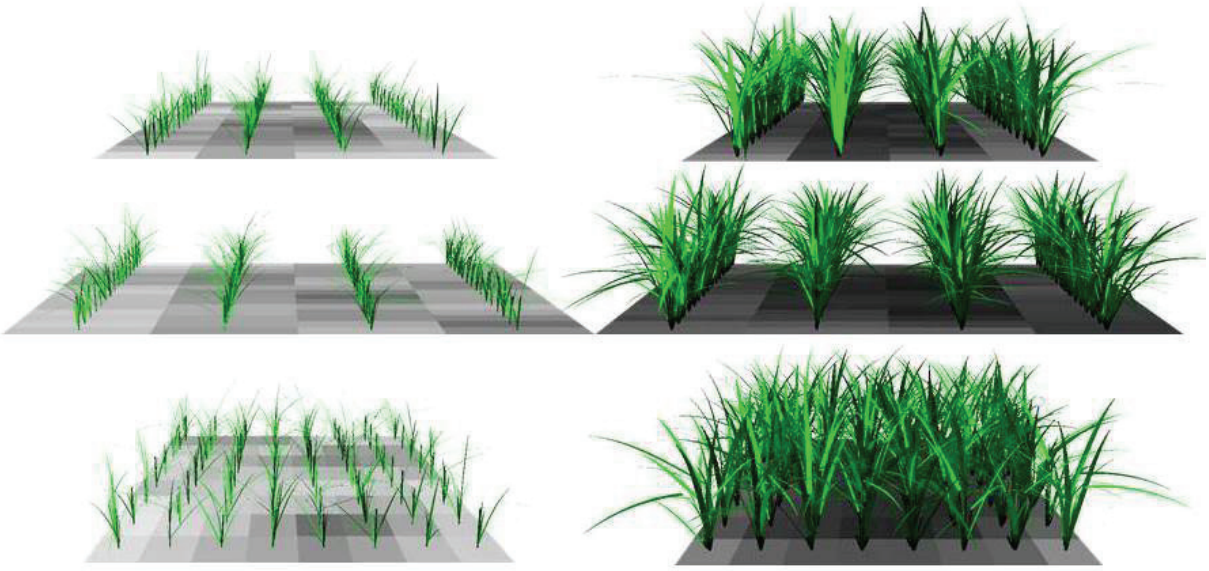

Figure 1. Visual output of simulated wheat canopies at 50 (left) and 80 (right) days after sowing, for three planting arrangements: 20 cm row spacing (top), 30 cm row spacing (middle), and a square-grid configuration (bottom). The population density was 125 plants m^{-2} for all configurations. The brightness of the soil tiles and canopy elements indicates the level of radiation reaching the element. The canopies shown here for illustration are smaller than those simulated to explore light interception (see text for details).

Results and discussion

The square-grid canopies intercepted less light then either of the row-based canopies (Figure 2). The average fraction of PAR interception from day 10 to 80 was 0.34±0.005 for the square grid, whereas for the row configurations this average was 0.37±0.006 at 20 cm and 0.38±0.014 at 30 cm row spacing. The simulated leaf area per m^2 of soil area was identical for all three planting arrangements due to the descriptive nature of the model used in this specific study. From this, we conclude that arranging plants in a square grid by itself reduces canopy light interception. This was unexpected, but may be explained by the more homogeneous distribution of leaf area in the grid configuration, which reduced the penetration of light into the lower canopy thereby reducing the total amount of light intercepted by the canopy compared to the row configurations. Light interception was similar for plants arranged in rows. Due to the fixed population density of 125 plants m^{-2}, plant-to-plant distance within rows was smaller at 30 cm compared to 20 cm row spacing. Apparently, increasing row spacing while proportionally decreasing plant distance within rows, results in the net effect on light interception being minimal. Similar results have been obtained for maize (Drouet and Kiniry 2008) for relatively narrow row spacing, but not for wider ones.

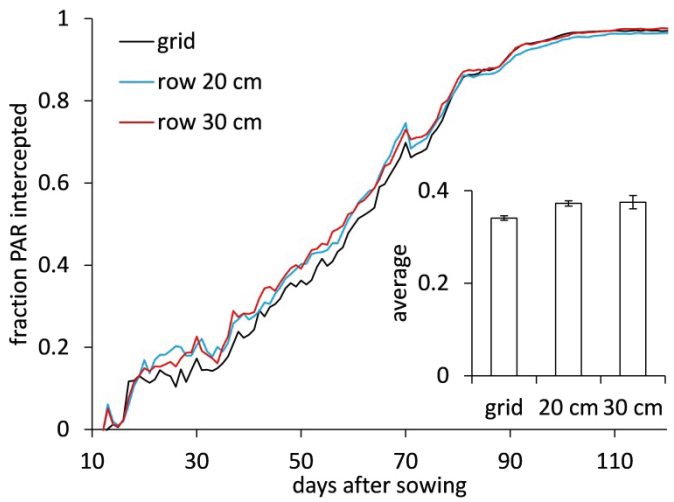

Figure 2. Daily simulated fraction of photosynthetically active radiation (PAR) intercepted by wheat canopies at 20 cm (blue line) and 30 cm (red line) row spacing, and in a square grid configuration (black line). Inset: average fraction of PAR intercepted between 10 and 80 days after sowing (error bars: 2 × se; n = 3).

In real canopies, plants may adjust their architecture in terms of leaf and branch angles, and tiller numbers, etc. in response to changes in canopy configuration including spatial arrangement and population density (e.g. Maddonni, Otegui *et al*. 2002), which is likely to affect light interception. Such plasticity was not accounted for in the approach taken here, in which fixed parameter values or parameter value probabilities derived from experimental data were used (Moeller, Evers *et al*. 2014). A fully mechanistic model that simulates plant growth and development based on the underlying processes such as photosynthesis and carbon allocation (Evers, Vos *et al*. 2010) will give flexibility in simulation of a range of densities and field configurations. An intermediate implementation in which the leaf area development is simulated empirically but tiller appearance and senescence is simulated based on environmental signals (Evers, Vos *et al*. 2007) may already cover most of the plasticity required for the simulations to provide an adequate representation of reality.

Architectural characteristics of one specific genotype (7770N) were input to the simulations shown here (Figures 1 and 2). However, genotypic differences in architectural attributes such as plant height, tiller number, and leaf size and angle have been described (e.g. Moeller, Evers *et al*. 2014). By including genotype-specific characteristics in a mechanistic model, the benefit of one architectural type over another can be assessed and quantified in respect to resource capture. Such models calibrated for Australian varieties with contrasting canopy architectures are currently being developed (Moeller *et al*. 2015)

Conclusions

The current exercise showed that management choices such as planting arrangement can be evaluated in relation to light interception using an FSP model. The approach can be extended to allow comparison of genotypes as long as genotypic differences in architectural characteristics are represented in the model parameterization. Once mechanistic models of the underlying physiology are included, the predictive power of FSP models could assist in exploring how architectural traits can be exploited in plant breeding by incorporating G x E x M considerations.

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3D modelling of tillering behaviour and light interception of freely (-*tin*) and restricted (+*tin*) tillering wheat near-isolines

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Abstract
A functional-structural plant model of wheat architecture was parameterised to simulate a pair of lines varying for a tiller inhibition (*tin*) gene. Effects of planting configuration were explored through red : far-red (R:FR) signalling on tiller production, final spike numbers, and light interception. Both increased plant density (125 to 200 plants/m^2) and row spacing (20 to 30 cm) reduced the simulated tiller and spike numbers per plant in both lines. This reduction was greater in the free-tillering (–*tin*) than in the reduced-tillering (+*tin*) line. At wider row spacing of 30 cm, simulated radiation interception was less in the +*tin* line than in the –*tin* line from about 60 days after sowing onwards. In the +*tin* line, increased R:FR signalling between individual plants due to less within-row spacing at wider rows resulted in reduced spikes/m^2 irrespective of population density. Spikes/m^2 simulated for the –*tin* line were similar at either row spacing in a population of 125 plants/m^2, but decreased with wider row spacing at the higher density of 200 plants/m^2. For both lines, the greatest number of tillers and ultimately spikes per m^2 was simulated at a density of 200 plants/m^2 and 20 cm row spacing (–*tin*: 820 spikes/m^2; +*tin*: 570 spikes/m^2). The simulations indicated that growing +*tin* wheat at an increased density of 200 plants/m^2 and 20 cm row spacing can produce similar, or greater, spikes/m^2 compared to –*tin* wheat grown at a density of 125 plants/m^2.

Key words
Functional Structural Plant Model, wheat, tillering, canopy architecture, plant density, row spacing

Introduction

Tillering is an important element of the canopy architecture in grasses such as wheat (*Triticum aestivum* L.). About 40 years ago, wheat with limited tillering was discovered in a farmer's field in North Africa (Atsmon & Jacobs, 1977). Since then, the tillering trait has been associated with a major gene named *tin* for tiller-inhibition. Genotypes with the *tin* gene (+*tin*) produce fewer tillers compared to genetically similar (near-isogenic) wheat lines without the gene (–*tin*). The reduced tillering trait is associated with an earlier cessation of tillering, reduced frequencies of later primary and higher-order tillers, and reduced leaf area. This behaviour may conserve soil moisture early in the season for later use when soil-water supply is frequently limiting in Australian growing environments. Because of their smaller canopies, +*tin* lines often intercept less photosynthetically active radiation (PAR) than freely tillering sisterlines (Mitchell et al., 2013; Moeller et al., 2014), which can limit productivity under favourable growth conditions.

Tillering plasticity is an adaptive mechanism by which individuals in a crop stand modify their architecture and physiological functions thereby responding dynamically to the availability of resources, chiefly light, water and nutrients. In conventionally tillering wheat (–*tin*), up to 60% of tillers can die under field conditions (Stapper and Fischer, 1990). While spike numbers are typically lower in +*tin* lines, on average about 10% more tillers become grain bearing spikes in +*tin* lines compared to –*tin* lines (Mitchell et al., 2013; Moeller et al., 2014). However, this increase in tiller economy may only improve, or maintain, yield if grain numbers per unit area (Fischer, 2008) are similar to those of conventional wheats with their lower tiller economy but greater tillering plasticity. A core determinant of grain number is spike number. This raises the question whether spike numbers and PAR interception, as discussed above, could be increased with a planting configuration (defined by combinations of plant population density and row spacing) that better suits the 'communal' rather than 'competitive' phenotypes associated with the presence of the *tin* gene.

Tillers die prematurely as a consequence of plant internal competition for resources. An important environmental signal for increased competition in a plant population is a lowered red / far-red intensity ratio (R:FR) of the light reflected by neighbouring plants. Low R:FR signals sensed at the plant base by specific photoreceptors results in the suppression of tillering in favour of elongation growth, which is a core aspect of

shade avoidance (Franklin and Whitelam, 2005). Moeller et al. (2014) reported that tillering in +*tin* lines ceased at a greater R:FR ratio than in –*tin* lines, and that this was independent of the observation that plant bases of +*tin* lines received more radiation and were exposed to greater R:FR than free-tillering sisters over much of the growing season. The aspect of tillering control associated with the R:FR signal was integrated into a spatially-explicit 3D model of canopy architecture, growth, and development called a functional-structural plant (FSP) model (Evers et al., 2007, 2015), which allows for the simulation of the feedbacks between the expanding canopy and light interception and scattering at the plant organ level. Here, an FSP model was parameterised to simulate a pair of near-isogenic lines (NILs) contrasting in the *tin* gene to subsequently explore effects of planting configuration through R:FR signalling on tillering, spike numbers, and PAR interception.

Methods

An existing FSP model of wheat architecture (Evers et al., 2007) was implemented in the simulation platform GroIMP (Hemmerling et al., 2008). The model simulates, on a daily time step, the development of the aboveground parts of the wheat plant in terms of leaf appearance, expansion, and senescence, tiller appearance and senescence, as well as geometrical properties such as leaf angle and curvature. Light interception by the canopy was simulated using the GroIMP stochastic path-tracer model, with direct and diffuse light coming from light sources arranged appropriately (Zhu et al., 2015). Further model stochasticity in the tillering response of individuals was caused by individual seed orientation. Tiller production was assumed to stop, and senescence was assumed to occur, at certain threshold R:FR values according to Evers et al. (2006, 2007) and Sparkes et al. (2006).

Details on architectural and physiological characteristics of the NILs 7770P (+*tin*) and 7770N (–*tin*) used for FSP modelling are given by Moeller et al. (2014). These NILs were developed by crossing a Silverstar-based, +*tin* line to the cultivar Wyalkatchem (–*tin*), and subsequent backcrossing to Wyalkatchem before inbreeding to produce BC1F5:6 plants heterozygous for *tin*. Plants were then self-pollinated to develop lines that are genetically similar (near-isogenic) except for the presence or absence of the *tin* gene. Briefly, the NILs were grown under well-watered and adequately fertilised conditions at a population density of 125 plants/m^2 and 20 cm row spacing in 2013 at Canberra. Architectural parameters were derived from detailed measurements taken on individual plants, and included leaf blade width and length, sheath length, and internode length for each phytomer and tiller type. The phyllochron was 85°Cd. Threshold R:FR values were calibrated for 7770N and 7770P considering the tillering dynamics as observed on an area basis in the field at 125 plants/m^2 and 20 cm row spacing. Data on leaf area index (LAI) and the fraction of intercepted noon-time PAR (fIPAR) were also taken on an area basis, and used only for comparison with model output.

Subsequently, simulations of tillering and canopy light interception were done for the NILs at four contrasting planting arrangements (Table 1). Tillering of individuals in the plant population responded to the average R:FR ratio simulated at 20 virtual sensors arranged around the base of each plant. The maximum expansion of leaves and internodes was entirely based on empirical rules, hence the same for each canopy configuration, and therefore the light intercepted was not used to drive growth. To eliminate border effects, only model output from the central area of the virtual plots was used in the analysis.

Table 1: Simulated planting configurations

Population density (plants/m^2)	Row spacing (cm)	Within-row spacing (cm)
125	20	4.00
125	30	2.67
200	20	2.50
200	30	1.67

Results and discussion

By integrating data describing the architecture of NILs contrasting in the *tin* gene and R:FR thresholds for the cessation of tillering and tiller senescence, the FSP model was able to dynamically simulate important differences in canopy structure between free- and reduced-tillering NILs as observed in the 2013 field experiment (Table 2). The simulated tillering dynamics deviated slightly from those observed in the field. The simulated tiller economy (calculated as the ratio of spike to maximum tiller number) was as a consequence the same for both NILs while the observed tiller economy of 7770P was 10% greater than

that of 7770N (Moeller et al., 2014). The arguably small deviations from observed tiller numbers in the simulations, and possibly other characteristics (e.g. leaf angle) influencing optical properties that were not considered in the model parameterisation, would affect the simulated light interception. This explains that at 125 plants/m2 and 20 cm row spacing, the simulated PAR interception was similar for both NILs while observed PAR interception was 3-10% lower in line 7770P than in 7770N for much of the growing season (Table 2, Figure 1). In the simulations, light interception was similar for both NILs at narrower row spacing of 20 cm, while at wider rows of 30 cm the *+tin* line 7770P intercepted less PAR than the free-tillering line 7770N from about 60 days onwards (Figure 1).

Table 2: Observed and simulated maximum tiller and spike number, leaf area index (LAI), and fraction of intercepted photosynthetic active radiation at the start of heading (fIPARZ50) in free- (7770N) and reduced-tillering (7770P) wheat near-isolines at 125 plants/m2 and 20 cm row spacing.

	7770N, *–tin*				7770P, *+tin*			
	Tillers/m^2	Spikes/m^2	LAI	fIPAR$_{Z50}$	Tillers/m^2	Spikes/m^2	LAI	fIPAR$_{Z50}$
observed	760 (20)	480 (21)	6.5 (0.3)	0.99 (0.02)	530 (19)	390 (25)	5.6 (0.6)	0.96 (0.06)
simulated	730	510	6.2	0.98	540	370	4.4	0.97

+/- one standard error of mean is given in parenthesis

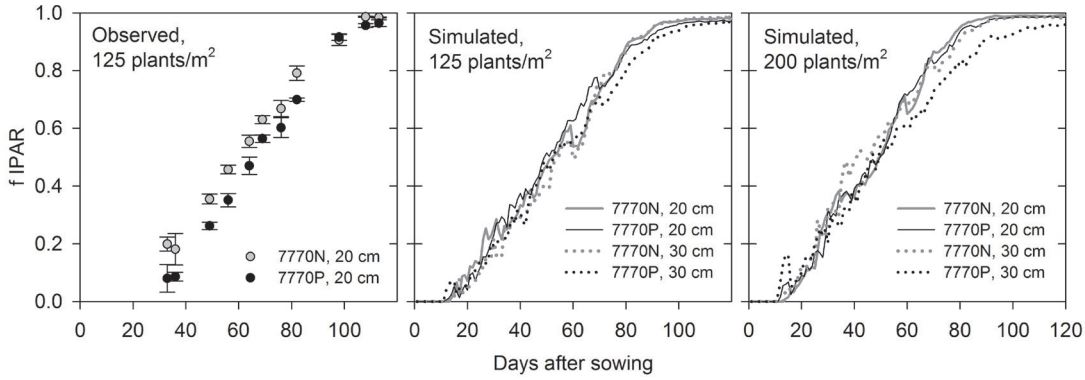

Figure 1: Observed and simulated fraction of photosynthetically active radiation intercepted at noon-time (fIPAR) in free-tillering (7770N) and reduced-tillering (7770P) wheat near-isolines at different planting configurations (see text and table 1 for details).

Both increased population density and row spacing are associated with plants within a row being closer together (Table 1) increasing the local low R:FR signalling, which acts as an environmental cue for future competition between neighbouring plants (Franklin and Whitelam, 2005). The increased R:FR signalling between individuals in the crop stand reduced the simulated tiller numbers, and ultimately spike numbers, per plant in both NILs (Figure 1). Similar responses in tiller and spike numbers to density and row spacing were previously reported for conventionally tillering wheat (Stapper and Fischer, 1990). At 20 cm row spacing, increasing the density from 125 to 200 plants/m2 decreased the tiller numbers per plant by only 0.4-0.5 tillers in both NILs. However, at wider rows of 30 cm, this decline in tiller numbers per plant was 2.4 tillers in the free-tillering line 7770N compared to 1.3 tillers in line 7770P (Figure 2).

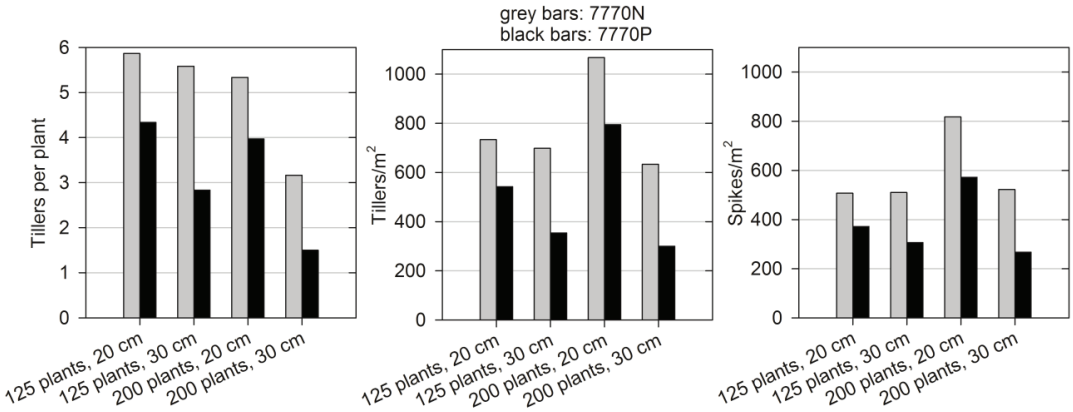

Figure 2: Simulated maximum tiller and spike numbers of free-tillering (7770N) and reduced-tillering (7770P) wheat near-isolines at four planting configurations (see Table 1 for details).

On a per area basis, the greatest number of tillers and ultimately spikes was simulated for both NILs at a population density of 200 plants/m2 and 20 cm row spacing (Figure 2). In the +*tin* line 7770P, increased signalling between individual plants associated with wider rows resulted in reduced spikes/m2 irrespective of population density. In other words, reduced tillering wheat performed better in terms of final spike numbers at narrower rows. In contrast, the final spike numbers of the free-tillering line 7770N were similar at either row spacing in a population of 125 plants/m2, and only decreased with wider row spacing at the higher density of 200 plants/m2. The simulation results also suggested that growing the reduced tillering lines 7770P at an increased population density of 200 plants/m2 at 20 cm row spacing can produce similar, or greater, spikes/m2 compared to the free-tillering line 7770N grown at a density of 125 plants/m2. Such information can inform the agronomy of *tin*-containing commercial cultivars, which are yet to be developed.

Conclusion

The FSP model allowed for the simulation of the most important trends in the tillering response of reduced- and free-tillering wheat near-isolines as associated with changes in light quality. Other aspects such as water and nutrient effects on tillering were not included here. The simulation results suggest that +*tin* lines are less well adpated to wider rows than free-tillering –*tin* lines as indicated by large reductions in spikes/m2 at wider rows. Fewer spikes can reduce grain numbers and ultimately yield. However, fewer spikes/m2 associated with reduced tillers and ultimately spikes per plant in the +*tin* line can be compensated for by increasing the population density but only at narrower row spacing. Further work will consider factors such as leaf angles that influence the optical properties of the canopies and consequently simulations of light interception, and include additional planting configurations to further explore interactions between genotype and management.

Acknowledgement

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Phenology, leaf and yield production patterns of sweet pepper under irrigated seasonal dry lowlands conditions, Papua New Guinea

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Abstract
Under seasonal irrigated dry-lowland conditions in Papua New Guinea (PNG), phenological parameters of three sweet pepper cultivars were quantified using thermal time after transplanting (°CdAT). First flowers appeared at 500-600 °CdAT, while green fruit maturity for harvest averaged 1200 °CdAT. Increase in leaf numbers and crop height were initially slow before increasing linearly from 400-800 CdAT, after which leaf production and plant height rates declined at 800-900°CdAT. Reduction of leaf production and plant height was attributable to assimilate distribution in favour high fruit production over vegetative structures and flower production. Fresh weight of marketable fruits was similar across cultivars; nevertheless, New Ace produced 87% of marketable fruit yield (but lower total yield) than Giant Bell and Wonder Bell, which had 74% and 80%, respectively. This study is complemented by investigating internal competition for photosynthate in sweet pepper to improve crop management practices for enhanced fruit retention and yield quality.

Key words
Biological growth pattern, Crop phenology, *Capsicum annum,* Thermal time

Introduction
Sweet pepper (*Capsicum annum* L.,) is an important vegetable crop in Papua New Guinea (PNG), with substantial market demand in urban centres and peri-urban areas. However, current production volumes of the crop are inadequate to meet the high and growing demand (Birch et al., 2011).

Sound vegetable crop management relies on an understanding of crop phenology in response to temperature and time. The mechanism of underlying variation in plant phenology within similar habitats remains nebulous (Elzinga et al. 2007). Modelling the influences of the local environment on crop phenology and yield could help with crop scheduling, reducing yield losses. For such a model to be developed it is crucial that crop phenology, allometry and the impact on yield be understood and quantified, and in many other models these parameters are related to thermal time (°Cd). No such model exists for sweet pepper, and certainly no detailed work has been conducted in PNG to quantify crop responses under local conditions.

This study quantified for three sweet pepper cultivars, leaf number, plant height, and flower and fruit numbers in relation to thermal time after transplanting under irrigated dry-lowland field conditions in PNG. The relationships between thermal time and phenological development were described using fitted equations.

Materials and Methods
Field experimentation was conducted at Pacific Adventist University (PAU) farm (S 09º24.309', E 147 º 16.343", 50m ASL) in June -October, 2013. Three sweet pepper cultivars (Giant Bell, New Ace and Wonder Bell) were selected and grown in experimental plots (3.6 m x 3.0 m) using a randomized complete block design (RCBD). Planting density was (0.4 m x 0.75 m) between and within rows with seedlings transplanted at 5 true leaves. The soil type was described by (Doyle, Birch, Sparrow, & Oromu, 2012). Two days prior transplanting, urea (46%N) was incorporated into the soil at half (275 kg/ha) of total application rate (550 kg/ha) along with triple superphosphate (19.2% P) at 450 kg/ha. At transplanting, a further application of NPK (18%N: 4.6%P: 0%K) was applied at 250 kg/ha as a top dressing. The remaining 50% of urea was equally applied at 25 and 45 days after transplanting (DAT).

The change leaf and branch numbers were recorded from tagged plants (n=5) within two inner rows of each plot at 4-6 days interval from emergence until maturity. Other measurements included plant height; number

of green and senesced (>50% of leaf area dead) leaves; the number of primary and secondary branches and internodes; the time of appearance and numbers of the first flower buds, flowers (petals fully open), fruit (>15 mm in length) and fruit maturity; and time to harvest maturity were undertaken. All measures were then related to thermal time after transplanting. Yield data was reported as green maturity while red maturity was determined from fruits on replicate plants. Data was collected every 4-6 days until fruit maturity.

All data analysis was performed using Statistix (Ver. 8.0) and R (Ver 3.2.1).

Results and Discussions

Crop phenology and thermal time

Overall observations revealed that there were differences in the duration of the phenological stages among the cultivars, with Giant Bell reaching defined phenological events later than New Ace and Wonder Bell (Table 1). These differences are important when selecting cultivars to manage environmental risks, for example, high temperatures during the onset of flowering and fruiting, and/or suitability for prolonged dry seasons. While the extended flowering period due to the indeterminate nature of sweet pepper provides an inherent plasticity, allowing plants to recover from flower loss, the availability of cultivars with differing patterns of phenological events provides additional capacity to manage environmental risks and address market needs and preferences. These considerations are important to modelling of sweet pepper development, and will require a means of quantifying phenotypic differences among genotypes. The use of a genetic 'constant' for phenological intervals e.g. transplant to first flowers, first flower to peak flowering, peak flowering to first green mature fruit may prove worthwhile.

Table 1. Mean thermal time after transplanting (°CdAT) for specific phenological stages of the three cultivars grown under hot humid conditions at the Pacific Adventist University farm, Papua New Guinea from June to November, 2013.

Cultivars	The phenological stages and duration in relation to thermal time after transplanting (°CdAT)						
	Flower Initiation	Early flowers	Early Fruits	Late flowers	Late fruits	Green fruit maturity	Red fruit maturity
Giant Bell	623a	645a	741a	1122a	1200a	1218a	1339a
New Ace	272c	529c	565c	842c	1009c	1195b	1220c
Wonder Bell	433b	584b	639b	970b	1058b	1146ab	1303b
$LSD_{(P=0.05)}$	60.08	49.99	30.84	53.99	75.34	54.69	9.22

Means values of thermal times followed by same letter within each phenological parameter did not differ based on Fishers Protected LSD.

Pattern of leaf and plant height and their relationship

From our observations, it is evident that there are differences among cultivars in plant height and number of leaves (Table 2). While it is not possible to attribute this to any specific process, the findings are consistent with those of Sun and Frelich (2011), though data here (Table 2b) do not contain the range of plant heights reported in that study (25-150cm). Leaf number and plant height for all cultivars were explained using a logistic regression model (> r^2=0.95) (Table 3). Crop height and the rates of leaf production declined after 1000-1100 °CdAT, presumably as assimilates distribution then favoured the production of fruits over vegetative structures and flower production. As this analysis has not previously been done in sweet pepper, further work to test this hypothesis is needed. From a commercial production viewpoint, it is vitally important to have plants that efficiently convert incident light into marketable product, and the ideal plant type is unlikely to be at the extremes mentioned by Sun and Frelich (2011). The work reported here used a much higher plant population (33, 333 plant per ha) than is currently used in PNG, but this population is unlikely to affect phenological development.

Table 2. The coefficients for logistic function relationship of growth parameters (leaf number and crop height) as function of thermal time. The estimates for fits were derived using logistic function, $f(x) = \frac{a}{1+exp^{(-b(Mt))}}$ $f(x) = \frac{a}{1+exp^{(-b(Mt))}}$**, where, *a* = the maximum curve of organs, and *b* = the steepness of the curve, *Mt* =growth rates, *M* = constant parameters, *t* = thermal time after transplanting.**

Growth Parameters	Cultivars	Coefficients of parameters as a function of thermal time after transplanting			Regression coef R-adjusted
		a ± *s.e*	*b*± *s.e*	*M*t*± *s.e*	r^2
a) Leaf number	Giant Bell	136.9±3.6	-4.1±0.62	0.006±0.0004	0.93
	New Ace	133.0±3.2	-4.0±0.30	0.006±0.0004	0.95
	Wonder Bell	169.0±2.6	-3.1±0.23	0.006±0.0003	0.94
b) Crop height	Giant Bell	54.8±1.1	-3.1±0.11	0.004±0.0002	0.96
	New Ace	48.0±0.5	-2.4±0.04	0.004±0.0008	0.98
	Wonder Bell	56.1±0.8	-3.1±0.11	0.005±0.0002	0.96

Means values of observed and estimated were significant based on Fishers Protected LSD $_{(P=0.05)}$.

Table 3. Coefficients for linear model relationship between plant height and leaf number production as a function of thermal time for three sweet pepper cultivars from vegetative stage to reproductive organ production and harvest period.

Cultivars	Coefficient of determinants using linear model function				Regression coef R-adjusted
	a(intercept)	*s.e*	$^{+}$*b(NOLF)*	*s.e*	r^2
Giant Bell	6.2811	0.7620	0.2869	0.0072	0.9919
New Ace	5.2921	0.9260	0.3354	0.0111	0.9859
Wonder Bell	5.9109	0.9502	0.2850	0.0108	0.9815
Cross cultivar	6.0281	0.6779	0.2979	0.0072	0.9772

∗Means coefficients were significant based on Fishers Protected LSD $_{(P=0.05)}$; $^{+}$NOLF is the linear rate coefficients of leaf number related to crop height extension.

Reproductive organ production and yield

The number of reproductive organs (flowers) produced followed a typical Bell-shaped curve while there was close to a nonlinear or sigmoid pattern for fruit number with the increasing °CdAT (Figure 1). New Ace produced a greater number of flowers earlier than the other cultivars. Later, after about 800°CdAT, Wonder Bell and Giant Bell produced a higher number of flowers than New Ace. This observation may be attributed to traits related to an increase in the number of sink organs (e.g. fruit), and changing source-sink ratios in the plants with increasing thermal time from transplanting (Heuvelink & Marcelis, 1996; Sun & Frelich, 2011).

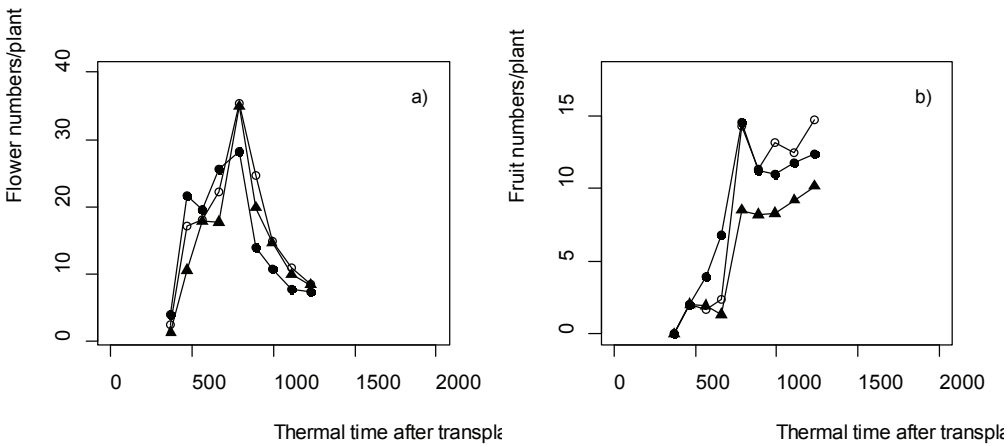

Figure 1. The progressive mean of flower (a) and fruit numbers (b) of three cultivars during sampling period. Each sampling dates are represented by symbols in three sweet pepper cultivars, New Ace (·), Giant Bell (▲), Wonder Bell (O) with number of flowers and fruits counted per sampling date, from the time of initiation of flowering to first flowering through to fruit maturity under seasonal irrigated dry-lowland conditions (range temperature of 30-35°C/18-21°C).

Marketable fruit yield was greater for New Ace, although this cultivar had lower total and net yields (Table 4). This discrepancy is explained by New Ace having larger individual fruit size. Giant Bell had the lowest number of marketable fruits and the lowest fruit number, and it is suspected that Giant Bell did not respond well to the high temperatures and prolong dry season, something observed earlier by (Marcelis, Heuvelink, Hofman-Eijer, Bakker, & Xue, 2004).

Table 4 Means of marketable and unmarketable fruit weight (grams/plant) and fruit numbers (fruits/plant) (n=5).

Cultivars	Fruit weight (g/plant)			Number of fruits (fruits/plant)			Percent of marketable and no marketable (%)	
	Total fruit weight (g/plant)	Marketable fruit weight (g/plant)	Unmarketable fruit weight (g/plant)	Total fruit numbers	Marketable fruit numbers	Unmarketable fruit numbers	Marketable fruits %	Unmarketable fruits
Giant Bell	773a	578a	194a	9b	6b	3a	74b	26a
New Ace	667b	576a	91b	13a	10a	2a	87a	14b
Wonder Bell	871a	674a	197a	15a	11a	4a	80b	23a
$LSD_{(P=0.05)}$	104.76	117.80	74.81	2.74	1.38	1.76	9.48	9.48

Mean values of fruit weights and numbers followed by same letter within each yield parameters did not differ based on Fishers Protected LSD.

This study has provided baseline information on phenology, development rate and timing for green maturity and red fruit maturity of three cultivars of sweet pepper grown in dry lowland conditions of PNG. The differences in crop phenology were thought related to genotype and /or multiple abiotic and biotic factors, and further studies are required to resolve the relative importance of these factors. The vegetative organ production and increase in plant height followed a sigmoid pattern, following a well-established pattern. However, flower and fruit production showed a different temporal pattern, being a typical 'Bell Shape'. Variation among yield was an indication of edaphic limitation or the effect of biotic or abiotic factors. However, fruit retention was evident and may be attributable to assimilate supply being limited by high temperatures, this possibly exacerbated by irrigation practices, and nutritional issues especially those (e.g. low phosphorus supply) reported by (Doyle et al., 2012).

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Floral morphology in rice grown under cold temperatures at booting and flowering and its effect on spikelet sterility

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Abstract
Booting and flowering in rice (Oryza sativa L.) are considered to be the two most sensitive stages to cold temperature stress. The controlled temperature glasshouse experiment compared a population of 120 genotypes from F6 Kyeema//Kyeema/NorinPL8 (KKN) when exposed to cold air temperature at the booting and flowering stages. The study aimed to examine the relationship between percentage of spikelet sterility (SS) and floral characteristics, namely the number of dehisced anthers (NoDA), anther dehiscence length (ADL), the number of pollen grains on stigma (PoS) and the anther length (AL) when subjected to cold temperature at the two development stages. Two sets of genotypes were sown 18 days apart and grown at 28/21°C day/night controlled temperature glasshouse, and were moved to the cold room (21/15°C day/night) at heading (set-1) and at early booting stage (set-2). A highly significant genotypic difference existed in percentage SS in both flowering (ranged from 49-100%) and early booting (4-99%) with flowering stage having higher average SS (88 vs 57%). A significant positive association existed between SS of flowering and booting (r=0.39**) with five genotypes performing consistently well. Highly significant negative correlations existed in both flowering and booting stage between SS and all the floral traits measured. Furthermore, multiple regression analysis indicated that 37% of the variation in SS was explained by the number of dehisced anther, anther dehiscence length and anther length when exposed to cold at flowering stage, while at booting stage the number of dehisced anther and anther length alone explained 58% of the variation in SS. The importance of the number of dehisced anther in explaining variation in SS has been highlighted and plays a significant role in cold tolerance.

Key words
Spikelet sterility, pollen, dehiscence, flowering, booting.

Introduction

The most sensitive stage of cold stress in rice is the booting stage, particularly the early pollen microspore stage (Satake and Hayase, 1970) followed by the flowering stage (Matsuo et al, 1995). Cold temperature during the two most sensitive stages directly affects spikelet sterility and leads to low grain yield. Meiosis which takes place at booting is susceptible to cold temperature and therefore affects pollen development (Matsushima, 1966). The early pollen microspore stage usually occurs 10 to 12 days prior to heading (Satake, 1976). Just after heading, flowering occurs and can take up to 5-7 days for all spikelets within a panicle to complete(Suzuki, 1982). Most spikelets flower in the morning, starting about 9am to 12:00 on a sunny day (Suzuki, 1982). Cold tolerance is often measured by spikelet sterility and is largely the result of damage of floral components leading to failure of fertilization (Nishiyama, 1984)

Matsui and Omasa (2002) under high temperature stress at flowering concluded that the reduction in the number of fertile engorged pollen in anther was the main cause for spikelet sterility. Fewer engorged pollen in anther led to less pollen swelling which resulted in anther indehiscence. Furthermore, under heat stress, Matsui et al (1999) reported that poor anthers dehiscence lead to reduced pollination and caused higher spikelet sterility and reduced grain yield. Matsui and Kagata (2003) examined that under heat stress the number of pollen grains deposited on the stigma was not influenced by the length of anther (ranged from 1.46 to 2.52 mm) and the length of apical dehiscence but was significantly correlated with the length of basal dehiscence.

This experiment was conducted to evaluate the cold tolerance of 120 genotypes (including 2 parents (Kyeema and NorinPL8) and Sherpa) at the booting and flowering stages, and to explore the floral characters contributing to spikelet sterility. The objectives of the experiment were (1) to determine genotypic variation in spikelet sterility within a population 120 genotypes of F6 KKN exposed to cold stress at the booting and flowering stages, (2)) to identify floral characters that are contributing to cold tolerance at the booting and

flowering stages, (3) to identify the cold tolerant genotypes at booting and flowering stage based on percentage of spikelet sterility, (4) to compare the consistency of line performance in the booting and flowering stages of the 120 genotypes.

Materials and methods

Two sets of the 120 genotypes were sown 18 days apart and grown under warm conditions (27/23°C day/night. The first planted set were moved to the cold temperature glasshouse 18/14°C at heading while the second planting at early booting stage for 14 days. Tube pots (5x5 cm and height 12 cm were filled with Gatton Black vertosol soil up to 1 cm from top of the pot and 1.0 g of slow release fertilizer (Osmocote plus 3-4 months: 16N–9P–12K) provided to ensure no nutrient limitation. Each tube was placed inside a second tube pot with 1.5cm cement layer in the base to reduce root escape. 5 seeds of each line were manually sown to a depth of 1.5 cm. Seedlings were thinned to leave 2 seedlings per tube at 11 days after sowing (DAS). This was then thinned to 1 seedling per tube at 15 DAS. Tubes were held in stable position within a wire mesh inside a water tank. Water level was gradually increased by 3cm every four days reach a final depth of 4cm above the soil surface with this flooded condition maintained for the duration of the experiment. During the growth period, the tubes were rotated weekly within replication to minimize any potential local influences including light and temperature.

Set-1 Flowering stage, on average 12 days after moving into the cold temperature glasshouse, 6 spikelets on the main stem panicle were randomly sampled shortly after floret opening , and from fixed positions the 3rd-5th spikelet at the 1st-5th upper branches for the booting stage cold (Set-2). Fresh spikelets were placed immediately into an empty petri dish, and stored at room-temperature. Sample processing was the same for both Set-1 and Set-2 with 3 spikelets out of 6 dissected. From each spikelet 6 anthers were examined for dehiscence and counted, 3 anthers randomly selected (from 6) were measured for anther length and anther dehiscence length under a stereo microscope using a digital micrometre. From the same spikelet, stigma was dissected and pollen on stigma counted. Stigma was stained with Iodine-potassium iodide solution (IKI; 0.5 g I2 and 2 g KI in 100 mL of H2). All data was analysed using Genstat 16th edition with genotype means compared using least significant difference (LSD 5%).

Results and discussion

SS induced by cold temperature at flowering stage was high (88%) and ranged from 49 to 100%, while at booting SS averaged 57% and ranged from 4 to 100%. A highly significant ($p<0.01$**) genotypic difference existed in SS and all floral traits measured at both development stages (Table 1).

Table 1. Percentage of spikelet sterility (SS), anther dehiscence length (ADL; µm), number of pollen grains on stigma (PoS), anther length (AL); and number of dehisced anther (NoDA); the minimum, maximum and mean value of the 120 genotypes at flowering (F) and booting (B) stages.

Genotypes	SS		Anther dehiscence length **(µm)**		The number of pollen on stigma		Anther length **(µm)**		The number of dehisced anther	
	F	B	F	B	F	B	F	B	F	B
Min	49	4	0	0	0	0	1056	704	0.0	0.0
Max	100	99	1237	1211	228	194	2168	2382	6.0	6.0
Mean	88	57	442	604	45	48	1747	1135	2.1	3.5
LSD (5%)	23**	29**	475**	468**	77**	80**	139**	479**	2.5**	2.7**
CV (%)	16	31	67	48	105	104	5	26	73.3	48.5
Cultivars										
Norin	86	4	857	856	93	52	1838	1219	5.8	5.8
Kyeema	97	56	206	362	28	3	1740	1080	2.0	2.0
Sherpa	79	30	951	577	214	52	1717	1287	2.5	2.5

Under flowering cold stress, Sherpa and Norin which are known to be cold tolerant cultivars had relatively high sterility at 79% and 86% (NSW Department Primary Industry, 2012; Saito et al, 2001). Compared to Sherpa, 21 genotypes had lower SS with the lowest SS achieved by line 12-223 (49%). Kyeema had 97% SS. The 20 most tolerant/susceptible genotypes had an average of 63% SS and 99% SS respectively. NorinPL8 was confirmed as the most tolerant cultivar at the booting stage which had only 4% SS while Sherpa and Kyeema had 30% and 56% SS respectively. A significant positive correlation existed between SS of genotypes exposed to cold at flowering and booting ($r=0.39$**) with Five genotypes performing consistently well (9-220, 9-229, 10-227, 10-230 and 11-227).

Anther dehiscence length (the sum of basal and apical dehiscence) ranged from 0 to 1237µm at flowering stage stress. Among the 3 cultivars, Sherpa and NorinPL8 had the longest anther dehiscence length at 951 and 857µm respectively, while Kyeema had the shortest dehiscence at 206 µm. There were 5 genotypes which had longer anther dehiscence length than Sherpa when dehiscence occurred under cold temperature conditions, 10-218 (1236 µm); 15-215 (1093 µm); 9-220 (1021 µm); 9-216 (1000 µm) and 10-230 (974 µm). In contrast, there were 6 genotypes which had no dehiscence at all (11-226, 11-229, 14-221, 13-220, 15-218 and 15-217). In flowering stage, dehiscence occurred cold exposure, however, the development of the panicle including pollen differentiation and development had all occurred under warm conditions, therefore the number of pollen in anther should have been able to reach genetic potential. The number of pollen in anther has been shown to be positively associated with pollen swelling which is hypothesised to be the driving force behind anther dehiscence (Matsui and Kagata, 2003). However, in the current experiment, with ample pollen produced under warm conditions the cause of indehiscence is likely to be the pollen swelling process itself was impaired. Indehisced anthers resulted in zero pollen grains deposited on the stigma.

At booting when dehiscence occurred under warm conditions after exposure to cold, NorinPL8 (856 µm) and Sherpa (577 µm) had longer dehiscence than Kyeema (362 µm). There were 25 genotypes which had significantly longer dehiscence than NorinPL8, ranging from 861-1211 µm. As a result of cold exposure at the booting stage 6 genotypes (different to those at flowering stage) had no anther dehiscence (10-218, 11-217, 11-219, 12-218, 12-220, 14-226).

The longer dehiscence the higher the possibility for pollen grains to be shed and intercepted by the stigma. Satake and Yoshida (1978) suggest that it is necessary to have 10 germinated pollen grains on the stigma to ensure successful fertilization. However, Matsui and Kagata (2003) examining rice under heat stress discovered that only 50% of the number of pollen grains on stigma germinate, therefore at least 20 pollens on stigma are necessary for successful fertilization, with 40 pollens on stigma considered as sufficient and 80 pollens on stigma as ample to ensure fertilisation. A similar result was found by Jagadish et al (2010) who revealed variation in spikelet sterility in heat stress at flowering stage was highly correlated with the proportion of spikelets with more than 20 germinated pollen grain on stigma. While in this experiment, the majority of genotypes a range of dehisce occurred and the minimum anther dehiscence length under flowering-cold-stress to ensure shedding of 40 pollen on stigma was 400µm, under booting-cold-stress this was 525µm.

In flowering-cold-stress, among the 3 cultivars, Sherpa produced the highest number of pollen on stigma (214). There was only one genotype, 9-216 which had higher number pollen on stigma than Sherpa. However 13% of genotypes had ample number of PoS (≥ 80 pollens) which should have sufficient pollen grains on stigma to maintain low SS%. While 66 of genotypes or 59% of genotypes under flowering cold had less than 40 pollens deposited on stigma, or higher possibility of unsuccessful fertilization.

In booting, 18% of the total genotypes had more than 80 pollens grains on stigma, with the highest number achieved by9-226 (194 pollens on stigma). While 32% of genotypes had more than 40 pollen grains on stigma and 50% of the population was considered to have sufficient pollen grains on stigma to ensure successful fertilization. However, 50% of genotypes had less than 40 pollen grains on stigma with 6% of genotypes having no pollen grains deposited on stigma. Anther dehiscence length had a strong positive correlation to the number of pollen grain on stigma both in flowering (r=0.82**) and in booting (r=0.68**).

When exposed to cold temperature, anther length was the floral trait with the largest difference between the two development stages. While Suzuki (1982) suggested AL to be important for cold tolerance Matsui and Kagata (2003) found that the number of pollen grains deposited on the stigma was not influenced by the AL which varied from 1.46 to 2.52 mm, but that the length of basal dehiscence (ranged from 0.26 to 0.58 mm) was significantly correlated to PoS.

When exposed to cold at flowering anther development was already completed and consequently anther length was unaffected by cold temperature stress and had an average of 1747 µm (1056-2168µm) while at booting stage cold stress effected anther elongation and resulted in a significantly reduced (by 36%) the anther length of 1135µm (704-2382) µm. This result supported the result of Suzuki (1982). The mean of anther length was greater at the booting stage indicating the adverse effect of booting stage cold on anther elongation.

Highly significant negative correlations existed in both flowering and booting stage between SS and all the floral traits measured (Table 2). The decrease in anther length (AL) at booting may lead to poor anther

dehiscence, however, in this experiment at booting-stage, the greater number of dehisced anthers may have compensated and resulted in sufficient number of pollen grains on stigma. The number of dehisced anthers at booting explained 56% of the variation in SS while at flowering stage the number of dehisced anther (NoDA) explained 33% of variation.

Furthermore, multiple regression analysis indicated that 37% of the variation in SS was explained by the number of dehisced anther (NoDA), the anther dehiscence length (ADL), and the anther length (AL) when exposed to cold at flowering stage, while at booting stage the number of dehisced anther (NoDA) and the anther length (AL) alone explained 58% of the variation in SS.

Table 2. Variation of SS in correlation to floral traits at flowering and booting.

Variables	F	B
DTH	0.41**	0.18ns
ADL (um)	-0.47**	-0.70**
Basal DL	-0.36**	-0.58**
Apical DL	-0.54**	-0.46**
PoS	-0.51**	-0.53**
AL (um)	-0.41**	-0.38**
No Dehisced Anther	-0.57**	-0.75**

Conclusion

Within the KKN population, all floral characteristics (anther dehiscence lenth, the number of pollen grains on stigma, anther length and the number of dehisced anther) had strong negative correlation to SS, both in Flowering and booting stages. The decreased AL at booting stage indicated the adverse effect of booting stage cold on anther elongation. The importance of the number of dehisced anther in explaining the total variation in SS, particularly at the booting stage was highlighted and plays a significant role in cold tolerance.

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Closing the gap: linking phenotype to genotype in rice lines contrasting for cold adaptation

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Abstract
Rice (*Oryza sativa* L.) production can be severely affected by low temperatures (15-19oC) during the reproductive stage. Previously a major quantitative trait loci (QTL) was mapped on chromosome 10 which explained 20.5% of the variation in low temperature induced spikelet sterility (SS) at the booting stage of an F2 Reiziq x Lijiangheigu (RL) population. Extreme bulks (10 tolerant and 10 susceptible) selected from the F2 stage were advanced to the F5 generation and again exposed to low temperature (24/15°C) for 14 days at booting and flowering stage. The objectives of this study were to determine i) whether lines identified as tolerant or susceptible to cold at booting at F2 generation maintained their classification at F5 ii) whether F5 RL lines identified as cold tolerant at the booting stage were also tolerant at the flowering stage and iii) whether lines identified as tolerant contained segregating markers in the vicinity of the previously identified QTL region.

SS at the booting stage (54.2%) was more severe than at the flowering stage (35.8%) indicating higher susceptibility to low temperature at booting. There was a positive correlation (r=0.62**) between SS at booting and flowering with 5 lines performing consistently well. There was also good consistency in performance across the generations with 8 of the F5 generation progeny lines maintaining high to medium tolerance (MT) to cold temperature at booting while 8 susceptible F2 lines were also susceptible at F5. SNP markers of potential importance were identified on chromosomes 5, 7 and 10. Lines containing the QTL region located on the short arm of chromosome 5 and 7, with Lijiangheigu as the allelic donor, had a reduction in SS of ≈ 25 and 27% respectively. Early generation selection in this population was effective for improving cold tolerance and the utilisation of a high density genome by sequence (GBS) marker system allowed the detection of additional QTLs which may prove useful in marker assisted breeding strategies.

Key words
Spikelet sterility, early generation selection, cold temperature stress, early microspore stage.

Introduction

The rice industry is based in the Riverina region in south-western NSW and while grown as a summer crop with temperatures reaching a mean daily maximum of 31oC in January (www.bom.gov.au), typically cold night air temperatures are a major cause of yield loss and variability. The optimum sowing time (October-November) for rice aims to ensure that the most cold sensitive young microspore stage occurs when night temperatures are the warmest in late January to early February. However, the probability of the crop experiencing night temperatures less than 15°C is as high as 80% in November and 50% in late February the latter coinciding with flowering (Farrell et al. (2006). Thus, there is value in identifying lines that have adaptation to cold tolerance across the whole reproductive period.

Ye et al (2010) reported that the QTL, qLTSPKST10.1, located within a 3.5 cM interval between SSR markers S10010.9 and S10014.4 on chromosome 10, could explain 20.5% of the variation in SS caused by low temperature treatment at the booting stage. In addition this QTL had a strong additive effect and could increase the SS by 14% in genotypes carrying the allele from Lijiangheigu. i.e. the allele from Lijiangheigu increased the SS, and allele from Reiziq decreased the SS. While a number of major genes have been reported to contribute to tolerance at the reproductive stage there is growing support that multiple genes are involved (Andaya & Tai 2006; da Cruz et al. 2013). It is more than likely that some tolerance genes are important across all growth stages while others provide tolerance to specific stages of development.

In this paper we examined a population which was known to possess a QTL with large additive effect to determine whether selection can be successful in early generation (F2 stage). In order to gain a much finer resolution of the chromosomal regions displaying segregation between the parents we have performed a bulk segregant analysis (BSA) with a genotyping by sequencing system (DArTseq), with the advantage of markers directly anchored to the sequenced genome of rice.

Materials and methods

Phenotyping

Two experiments, flowering stage cold stress, and booting stage cold stress, were conducted in a controlled temperature glasshouse at the Gatton Campus of The University of Queensland (Latitude: -27.554404 | Longitude: 152.33864) from March to September 2014. In both experiments, 25 genotypes consisting of five varieties (Reiziq, Lijiangheigu, Kyeema, Norin PL8 and Sherpa) and 20 (10 tolerant and 10 susceptible) F5 lines derived from single seed descent were advanced from the F2 generation of RL cross (Ye et al. 2010), except for 1 susceptible line which was lost during the flowering stage experiment. The tolerance or susceptibility of each line was determined by SS in F2 generation and was on average 13.8% (all <17%) and 80.6% (all >73%) for the two extreme bulks respectively. Lijiangheigu, is a medium grain rice originated from Lijiang (alt. 2390m a.s.l.), China and is considered cold tolerant at all growth stages (Ye et al. 2009) and NorinPL8 is a Japanese cold tolerant parental line (Saito et al. 1995). Reiziq, Sherpa and Kyeema are Australian varieties with Sherpa considered quite tolerant to cold temperature stress at the reproductive stage (Troldahl et al. 2014).

Each experiment was conducted in a completely randomized design with three replicates. All plants were grown in a warm room (30ºC/19ºC ±2oC day/night) except for 14 days of cold treatment (24°C/15°C day/night). The maximum temperature in the cold room varied between 22.0 and 27.6°C while the night time temperature was constant throughout the experimental period. In the flowering stage experiment, each pot was moved into the cold room when the individual plant reached the heading stage. The booting stage experiment was planted 17 days after the flowering stage experiment, and when 2 out of 3 replications of a line in the flowering stage experiment had reached the heading stage, all three replications of the same line in the booting stage experiment were moved into the cold room.

Plastic tube pots (50x120mm) were filled with 250 ml of alluvial Lockyer prairie soil consisting of light, black clay (Isbell 2002). Five seeds were sown in each pot and seedlings thinned to leave one plant per pot 16 DAS (days after sowing). Initially seedlings were grown aerobically and 14 DAS, the water level was increased gradually (2 cm every 3 days) until 31 DAS when the water level was maintained at 4 cm above the soil surface. One gram of slow release Osmocote® Pro 3-4M fertiliser (17N-11P-10K-2MgO-TE) was applied to each pot before sowing. Iron sulphate was sprayed twice at 27 and 47 DAS as the plants started to show symptoms of iron deficiency.

Head emergence was defined as the emergence of the first spikelet from the sheath. When the first spikelet protruded at least 2cm from the sheath's base on the main stem panicle, but before flowering, the main stem was tagged and plants transferred into the cold room for the flowering stage. The number of filled spiklelets; unfilled grain i.e. spikelets that developed hull but were empty; and dead spikelets i.e. spikelets that failed to develop hull of spikelets on the main stem panicle were counted for each line. SS was calculated as 100 (%) – filled grain (%). All data were statistically analysed using Genstat V14.

Genotyping

Genomic DNA was extracted from young leaf tissue sourced from each line utilising the hexadecyltrimethylammoniumbromide (CTAB) technique, as described by Rogers and Bendich (1985). DNA was prepared for genotyping according to the recommendations of diversity arrays technology (www.diversityarrays.com) and genotyped utilising the DArTseq system and Rice array (Oryza sativa). The model genome used in sequence alignments was sourced from Phytozome assembly v9 downloaded from ftp://ftp.jgi-psf.org/pub/compgen/phytozome/v9.0/Osativa/assembly/. Marker data was compiled and analysed utilising Microsoft Office Excel 2007, with markers containing ≥ 20% missing data removed. After sorting lines according to phenotypic score for SS, markers were filtered for clear segregation patterns between the tolerant and susceptible lines and their respective parents. This consisted of a minimum of 65% of lines in both the tolerant and susceptible group sharing one or the other parental genotypes. For DArT markers, only those that had at least 2 or more markers consecutively located within 50,000 physical map units of each other were retained and for SNPs, at least 1 DArT marker within 50,000 physical map units of a SNP were retained.

Results and Discussion

Genotypic consistency in performance (SS) between flowering and booting stage stress

There was a highly significant ($p<0.001$) positive correlation in SS between the flowering and booting stages ($r=0.62^{**}$; Figure 1). Significant positive correlations across growth stages have been reported previously by Ye et al (2009) among others when examining response of varieties. Herein we show similar positive correlations

are observed when working with a population of lines from a single cross and offers the promise of an underlying tolerance regardless of potential physiological mechanisms involved. While the importance of cold temperature events at the booting stage is recognised by the Australian rice growing region, cold temperatures at flowering could also be a major issue and general tolerance across development stages would be beneficial. Almost all genotypes that were susceptible at the flowering stage performed similarly at the booting stage e.g. RL-37, RL-232 and RL-243. Similarly, some genotypes that were tolerant at flowering stage were also tolerant at the booting stage e.g. Lijiangheigu, Norin PL8, Sherpa, RL-10 and RL-11. As noted by Ye et al 2009, Lijiangheigu has undergone long-term natural selection for cold tolerance as it originates from high elevation areas and could explain cold tolerance for all growth stages.

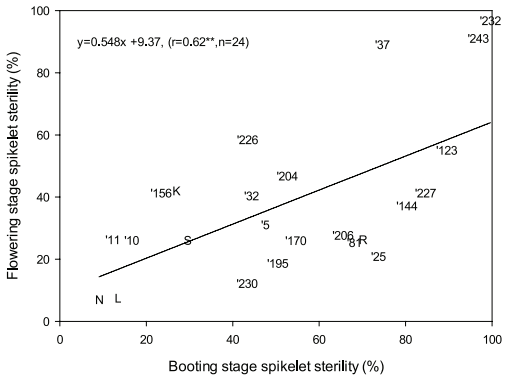

Figure 1. Relationship between spikelet sterility when 24 lines were exposed to cold temperature (24/15°C day/night), for 14 days at booting and flowering stages. Numbers are consistent with Line code numbers listed in Table 1 while varieties are abbreviated with first initial: R= Reiziq; L= Lijiangheigu, N= NorinPL8; S= Sherpa, K= Kyeema.

Table 1. Variety, tolerance and susceptibility classification of 22 lines at F2 and F5 generation based on percentage spikelet sterility (SSB) exposed to cold temperature (24/15°C, day/night) for 14 days at booting stage. Presence (√) or absence (X) of cold tolerant enhancing alleles donated from either Lijiangheigu (L) or Reiziq (R) is noted for 3 QTL regions identified by DArTseq analysis.

Line code	@ F2	SSB(%)	sig	@ F5	Chr 5 (L)	Chr 7 (L)	Chr 10 (R)
RL-11	T	12.2	a	T	√	√	√
Lijiangheigu	T	13.4	a	T	√	√	X
RL-10	T	16.6	ab	T	√	√	√
RL-156	S	23.4	abc	T	X	√	X
RL-230	S	43.3	abcd	T	√	√	√
RL-226	T	43.4	abcd	T	√	X	√
RL-32	T	44.3	abcde	T	√	X	√
RL-5	T	47.5	abcde	T	√	√	X
RL-195	T	50.4	bcdef	T	√	X	√
RL-204	T	52.6	bcdef	MT	√	√	√
RL-170	T	54.6	cdefg	MT	X	√	√
RL-206	S	65.5	defgh	S	√	√	X
RL-81	S	68.1	defgh	S	√	X	X
Reiziq	S	70.1	defgh	S	X	X	√
RL-25	S	73.7	defgh	S	X	X	X
RL-37	T	74.6	defgh	S	X	√	√
RL-144	S	80.3	efgh	S	X	√	X
RL-227	S	84.6	fgh	S	X	X	X
RL-109	S	85.1	fgh	S	X	X	√
RL-123	T	89.5	gh	S	X	X	√
RL-243	S	96.8	h	S	√	X	X
RL-232	S	99.6	h	S	X	X	X
Mean		54.2**					
LSD (5%)		36.6					
CV (%)		41.1					

Genotypic consistency in performance between F2 and F5 generation in booting stage stress and QTLs

Mean SS under the booting stage cold was 54.2% at the F5 generation (Table 1). The mean sterility of progeny lines that were selected as tolerant at F2 stage was lower than that selected as susceptible (48.6 vs 72.0%). Among the 10 progeny lines that were tolerant in F2 generation, 7 had lower SS than the mean of 25

genotypes. Comparatively, among the 9 progeny lines that were selected at F2 as susceptible, only 2 (RL-156 and RL230) had sterility less than the mean. Four varieties had sterility less than 30% while Reiziq had a high sterility of 70.1%. Sterility of lines RL-10 and RL-11 (16.6 and 12.2%) were similarly as low to the strongly tolerant varieties Lijiangheigu and Norin PL8 (13.4 and 9.1%). Some progeny lines such as RL-10, RL-226, RL-32 and RL-11 were cold tolerant, while others such as RL-243 and RL-232 were susceptible at both generations. Thus, SS of 20 lines exposed to cold at booting stage at F5 generation had a significant ($p<0.05$) positive correlation ($r=0.47^*$) with SS determined at the F2 generation, suggesting that additive effects were large.

As noted by Cruz et al. 2013 when non-additive effects are large, selection should be applied in advanced generations of breeding programs (F4 or F5 stage).

A total of 14,563 SNPs were generated and analysed utilising DArTseq. Initial data filtering revealed significant distinctive haplotypes on chromosomes 3, 5, 7, 8, 10 and 11. Of these, only three of the genomic regions had a predicted significant effect on SS% and these were located on chromosomes 5, 7 and 10. Eight lines classified as tolerant (T & MT) at the F5 generation contained the Reiziq allele at the qLTSPKST10.1 QTL while 8 of the susceptible lines had the allele from Lijiangheigu. A significant phenotypic difference in SS existed between those lines that contained the allele from Reiziq or Lijiangheigu at this QTL on chromosome 10 (48 vs 73%). The genomic regions on chromosome 5 and 7 donated by Lijiangheigu, had an average of 49 and 47% SS in tolerant lines and 74% SS in susceptible lines harbouring the Reiziq allele. When the additive effect of genomic combinations was considered, four lines had the tolerant allele from the genomic regions on chromosome 5, 7 and the QTL on chromosome 10 which resulted in SS of only 31%.

Conclusion

There was consistency in performance across the F2 and F5 generations. Four genotypes had sterility less than 30% with lines RL-10 and RL-11 strongly tolerant. This result demonstrates early generation selection was effective for improving cold tolerance in rice within the RL population where the parental line Lijiangheigu, is a line considered to have a general cold tolerance across growth stages and where additive effects appear large. Whether cold tolerance donated by this line holds true in populations of a different genetic background requires further investigation. There was also consistency in performance of the F5 RL lines between exposure to cold temperature at booting and flowering stages with 5 genotypes performing consistently well. In addition to the QTL identified on Chromosome 10 there were two other regions identified as potentially offering improvements in cold tolerance on Chromosome 5 and 7. When the additive effect of combinations of genomic regions and QTL was considered, lines that had the tolerant allele on chromosomes 5 (L), 7 (L) and 10 (R) conferred significant tolerance to cold exposure at booting. The results of this work suggest that the incorporation of Lijiangheigu material into the breeding program will provide general improvement in cold tolerance.

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Predicting heading date and frost impact in wheat across Australia

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Abstract
Spring radiant frosts occurring when wheat is in reproductive developmental stages can result in catastrophic yield lost for producers. In wheat, heading time is the main determinant to minimize frost risks and to adapt new frost-tolerant cultivars to target population environments. Gene-based phenology models provide robust tools to predict heading times based on alleles of VRN and PPD genes, and have been widely validated across Australian wheatbelt for most of commercial wheat cultivars. A field experiment was conducted at Gatton in 2014 to calibrate the gene-based model for newly released cultivars. The results indicated that one field experiment including extended photoperiod and pre-vernalization treatments can be used to parameterize new cultivars and allow accurate prediction of heading time across all Australian environments using our gene-based model. Across Australia, we found that yield could be improved by up to 20% on average if frost tolerant lines were available. The yield increase resulted from (1) reduced frost damage and (2) the ability to use earlier sowing dates. Simulations suggest that a small reduction in the threshold temperatures, equivalent to frost tolerance of 1°C lower than current cultivars, would have a large effect in the west of Australia. In the east, frost tolerance to lower temperatures (~ −4°C) would be required to maximise the yield advantage.

Key words
Post head-emergence frost, reproductive frost, spring radiant frost, climate change, crop modelling, APSIM, crop adaptation, breeding, flowering.

Introduction
Frosts at reproductive stages are catastrophic events for wheat crops and a single frost event has the potential to destroy grain yields by killing entire heads (Frederiks et al. 2012). Post-heading frosts are common in sub-tropical areas but can also occur in Mediterranean and temperate regions (Fuller et al. 2007). In Australia, reproductive frosts commonly result in 10% yield penalties, but in affected districts yield losses greater than 85% have been observed (Paulsen and Heyne 1983; Boer et al. 1993). In wheat, heading time is the main determinant of minimizing frost risks and adapting new cultivars to the target environments. Gene-based phenology modelling provides robust tools to predict heading times based on alleles of VRN and PPD genes, and has been widely validated across the Australian wheatbelt for most current Australian commercial wheat cultivars (Zheng et al. 2013). In order to do a national assessment of frost impact, the APSIM 7.6 model was adapted to predict impacts of post-heading frosts (Zheng et al. 2015). The aims of this study were to: (1) calibrate the phenology of cultivars for the model using pre-vernalisation and extended photoperiod trials, (2) characterise climatic trends in frost events at critical times for wheat over the last six decades, and (3) estimate the comparative benefits that breeding for tolerance to post-heading frost would bring to the wheat industry in Australia.

Material and Methods
In a previous study, 210 lines were phenotyped to simulate heading dates with a gene-based model in Australia (Zheng et al., 2013). In the current study, a field experiment was conducted at Gatton in 2014 to calibrate an additional 56 newly released cultivars. The experiment included four treatments, namely (1) natural vernalisation and natural photoperiod, (2) natural vernalisation with extended photoperiod, (3) pre-vernalisation and natural photoperiod, and (4) pre-vernalisation with extended photoperiod. These treatments were used to estimate the gene-effects of major VRN and PPD genes as described in Zheng et al. (2013).

To better understand the spatial and temporal variability of frost events, 0.05°gridded weather datasets were used to calculate frost occurrence and frost impact on wheat production across the Australian wheatbelt from 1957 to 2013. Yield impact was simulated at 60 key locations with representative management practices (Chenu et al. 2013)using the APSIM-Wheat model with a newly-developed frost module.

Results and Discussions

Prediction of wheat heading time using a gene-based model

Simulations for an independent set of data closely reflected observations of heading times, for trials spread across the Australian wheatbelt from 1985 to 2014 (Fig. 1; RMSE = 5.95 d, N = 811 for 56 new genotypes RMSE = 4.76 d, N = 5792 for genotypes in Zheng et al. 2013; RMSE = 4.92 d, N = 6603 for all 266 genotypes). The results indicated that a single field experiment including extended photoperiod and pre-vernalisation treatments can be used to calibrate new cultivars and allow accurate prediction of heading time across all Australian environments using our gene-based model. This model was used to assess the impact of post-heading frosts across Australia.

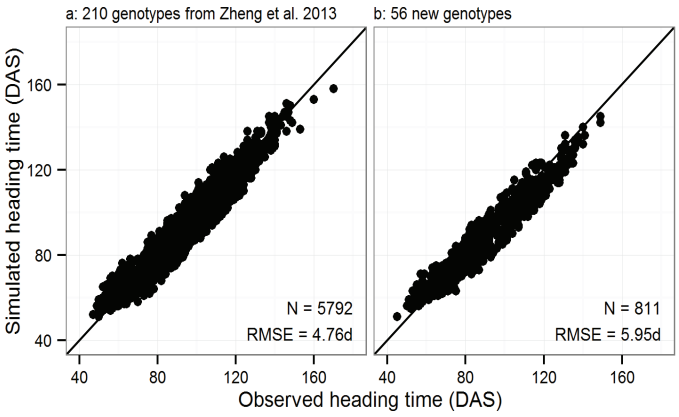

Fig. 1 Comparison between observed and simulated heading times for (a) 210 cultivars as published by Zheng et al. (2013), (b) 56 newly parameterized genotypes evaluated for an independent dataset (validation) comprising trials from 1985 to 2014 across the Australian wheatbelt. Heading time is expressed in days after sowing (DAS).

Frost limits achievable yield in a large part of the Australian wheatbelt

During the past six decades, a significant increased number of frost events ($P < 0.1$) has been recorded for several areas in the Australian wheatbelt (Fig. 2b; Zheng et al., 2015)). For instance, up to an extra 0.5 frost day per year has been recorded on average in higher altitude areas. While most of the western and southern parts of the wheatbelt have seen a slight increase in the number of frost days, decreases in frost occurrence were observed across almost half of the eastern part of the wheatbelt. Significant delay in last frost days ($P < 0.1$) were also recorded particularly in the south, south-eastern and western parts of the wheatbelt, with shifts up to 1.4 days later per year occurring in the South and West (Fig. 2c). A significant yield decrease was simulated in about a third of the wheatbelt due to more frost days and/or a delay in the occurrence of the last frost day (Fig. 2d).

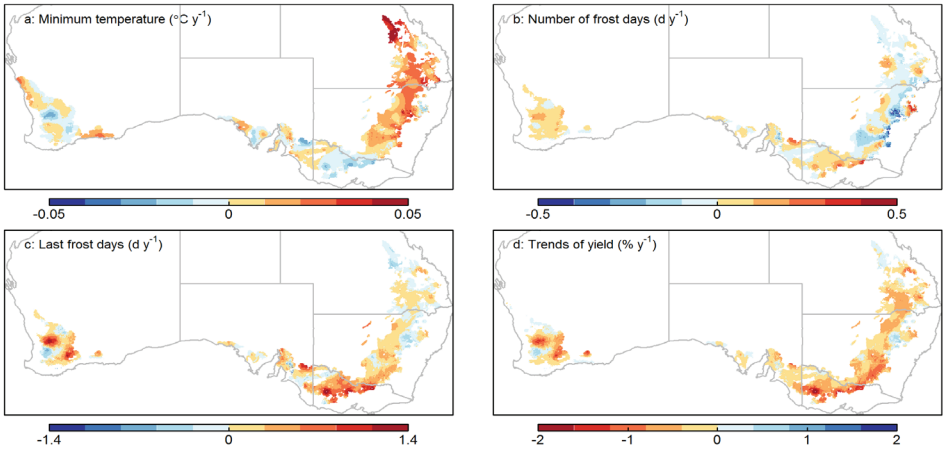

Fig. 2 Temporal trends in (a) season minimum temperature (average from May to October), (b) number of frost days (annually), (c) timing of the last frost day and (d) yield for the mid-maturity cultivar Janz sown at 18-May. Data from 1957 to 2013 across the Australian wheatbelt. Figure adapted from Zheng et al. (2015).

Potential benefits of developing frost-tolerant genotypes

The level of frost tolerance required to achieve greater yield was examined in silico for frost tolerance from 0°C to -5°C (ideotypes). Most potential benefits occurred by decreasing the frost damage threshold temperature from 0°C to just -1°C in the West, and from 0°C to -3 or -4°C in the East and South-East. Extra yield improvement may be gained in the East and South-East with the opportunity to exploit earlier sowing times, i.e. exploit longer growing seasons with less terminal drought ('Direct plus indirect impact' of frost, Fig. 3). Yield advantages of up to 1 t ha^{-1} extra yield were predicted in parts of the East and the West (Fig. 3).

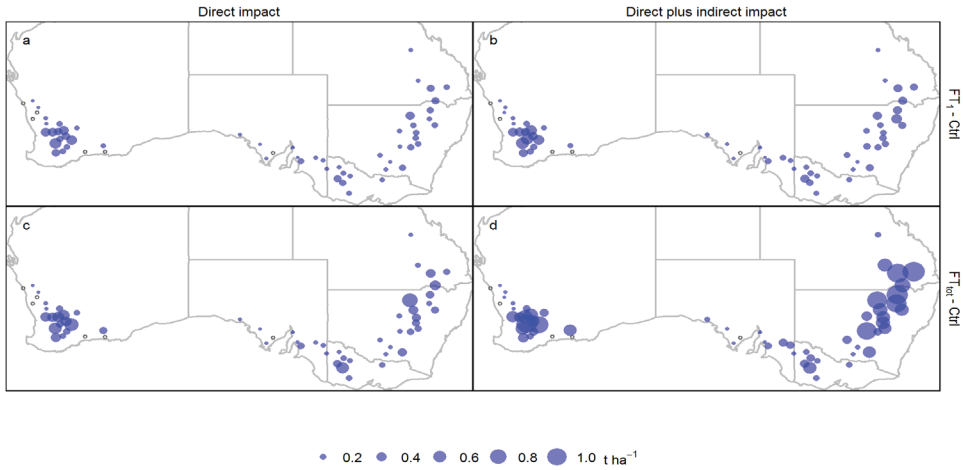

Fig. 3 Simulated yield advantage of mid-maturing cultivars when increasing the frost tolerance to -1 °C (top maps (a-b); "FT_1 – Ctrl") or to a total tolerance (bottom maps (c-d); "FT_{tot} – Ctrl"). To assess the "direct impact" of frost (a and c, left), simulations were performed at the optimum sowing date for the current frost damage threshold (0 °C, i.e. 'control'), and at the optimum sowing date specific to each frost-tolerance level to assess additional gains that are allowed by opportunities of earlier sowing ("direct plus indirect impact" of frost; b and d, right). Simulations were done for 1957-2013 at 60 locations. Figure adapted from Zheng et al. (2015).

Small changes in frost tolerance could greatly improve national yield

Improving frost tolerance from 0°C (Control) to -1°C (FT_1) increased the estimated national yield of a mid-maturing cultivar by about 7% when considering direct impacts (frost damage), and by about 10% when considering, in addition, indirect impacts (with earlier sowing to optimise yield potential). Further yield advantages were simulated by increasing frost tolerance level to -2°C (FT_2) and -3°C (FT_3). A similar trend in yield gains was estimated for all the tested genotypes regardless of their maturity type. Frost immunity (total frost tolerance) increased the average simulated yield of early, mid and late-maturing cultivars by as much as 9.8%, 10.8% and 10.7% for direct impact alone. When both direct and indirect impact were included, yield

increases were even greater at 19.6%, 21.1% and 18.2%, respectively (Fig. 4).

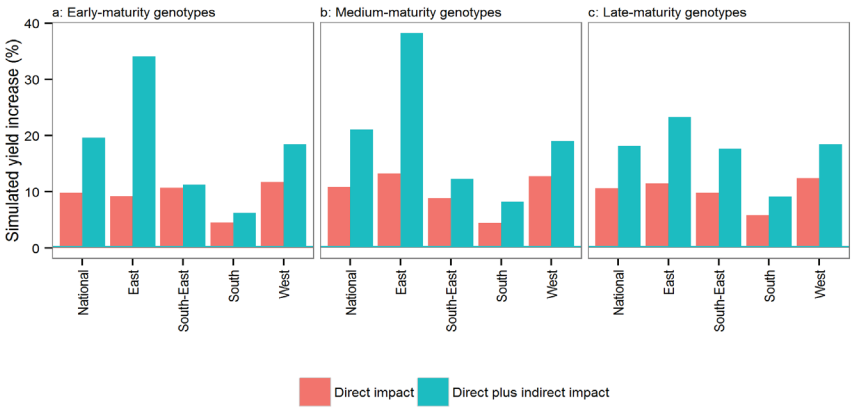

Fig. 4 Simulated yield increase due to (i) direct frost damage or (ii) direct damage plus the opportunity benefits of early sowing for the four major cropping regions of Australia and for national production. Simulations for early-, mid- or late-maturing cultivars performed for the optimum sowing dates as detailed in Fig. 3.

Conclusion

While counter-intuitive, global warming may actually increase the risk of frost by accelerating wheat phenology, with heading time occurring earlier, during the frost-prone period. To reduce frost risks, a gene-based model is now available to adjust farmer management for newly released cultivars. From the simulations performed with this model, it appears that breeding for improved tolerance to post-heading frost could allow ~20% yield increase in Australia (Fig. 4), as direct frost damage could be reduced and as crops could be sown earlier to reduce risks of late-season drought and/or heat stress.

Acknowledgements

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Modelling the impact of frost on wheat production in Australia

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Abstract
Frost can significantly reduce crop yields representing a management challenge for grain producers. In Australia, there has been an increased frequency of frost across much of the southern grain belt between 1960 and 2011, with the current trend of increased frost days in some regions expected to occur until the mid-2030's. In southern Australia, growers need to manage the competing risks of frost around flowering while avoiding heat stress and terminal drought during grain fill. While we can use crop models to help growers understand and manage these competing aims by identifying the risk of climatic events coinciding with key growth stages, we don't generally predict the impact of frost on yield. Although frost damage has been incorporated into a number of crop models through winterkill functions, seedling death or advanced senescence, the non-linear reduction in yield potential associated with reduced grain number due to an anthesis frost is not incorporated into current crop models. Therefore we need to improve model capability to account for frost damage and the subsequent impacts on yield. This paper presents a preliminary frost response function developed from the literature, which aims to capture the effect on grain number (and subsequent yield impacts) of frost events around anthesis. The preliminary frost model was incorporated into the Catchment Analysis Tool (CAT, DEDJTR Victoria) and applied across Victoria. Results from the application of the frost model are presented.

Key words
Crop models, CAT, frost, wheat

Introduction

In Australia, wheat production occurs on over 13 million hectares, producing 19 MT of wheat per year (based on a five year average to 2010/11: ABARE, 2012). Crop production across Australia is being increasingly impacted by climate as the average annual daily mean temperatures have increased progressively since the middle of the 20th Century against a backdrop of natural year to year variability (CSIRO and Bureau of Meteorology, 2012). One of the challenges for crop production is the change in climate extremes, including the increased incidence of frost across the Australian grain belt between 1960 and 2011 (Crimp, 2014). Frost reduces crop production and represents a substantial economic loss to the industry, with direct losses estimated to be at least $120 million per year. Damage to wheat from frost has been observed in all stages of growth from seedlings through to maturity. However, in Mediterranean type climates, frost around anthesis has the greatest potential yield impact, with 10-100% yield loss observed in the literature. Frost around anthesis results in partial or complete sterility of florets and whole spikelets and therefore reduced grain number and yield (Al-Issawi et al., 2012). While we can use crop models to help growers understand and manage the risk of frost coinciding with key growth stages, we don't generally predict the yield impacts. Although frost damage has been incorporated into a number of crop models through winterkill functions, seedling death or advanced senescence, the non-linear reduction in yield potential associated with reduced grain number due to an anthesis frost is not accounted for in current crop models.

The Frost Model

Based on a review of the literature (Barlow *et al*., 2015) a frost model was developed that reduces grain number and therefore yield potential in response to frost around anthesis. The model (Figure 1) includes a calculation of the percentage reduction in grain number in response to a frost event around anthesis; and a statistical distribution of impact over time. The standard method to determine if a frost event has occurred uses a criterion of 2.2°C (measured within a Stevenson Screen at 1.2m above ground level). This temperature is known to cause frost damage in flowering crops, as temperatures at canopy height are invariably lower (2 to 4°C) than those in the Stevenson Screen (Frederiks et al., 2008). In this paper the minimum temperature

(1.2m Stevenson screen) to trigger frost damage was set at either 2°C or 1°C. The reduction in grain number was scaled from 0% loss at the set minimum temperature to 100% loss potential over a 4°C temperature drop, to either -2°C or -3°C depending on the initial temperature (Figure 1a). Once the maximum reduction in grain number is determined, a stochastic distribution of around 50% at anthesis was used to scale the yield reduction. This ensures that the maximum reduction in grain number only occurs at around 50% anthesis, with the losses scaled around 50% anthesis to reflect the variation in the timing of anthesis within a single plant as well as across a paddock and the sensitivity of the plant to frost. These two response functions are multiplicative and used together predict the reduction in yield. This model captures the largest impact from a single frost event during the 14 day anthesis window and does not account for multiple frost events, or frost outside the defined anthesis window.

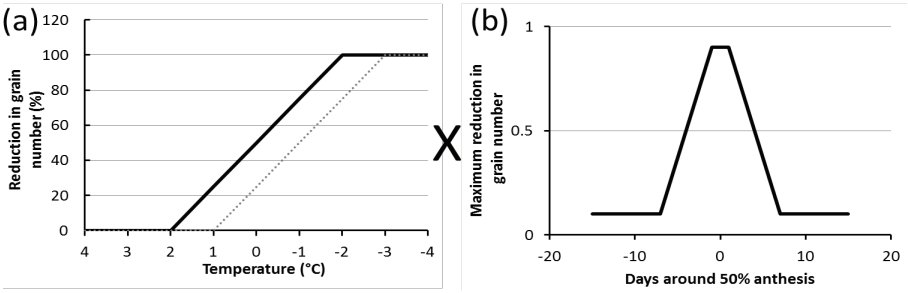

Figure 1. Frost model which describes the reduction in grain number in response to minimum daily temperature (as defined by 1.2m Stevenson Screen), with (a) the reduction in grain number observed at anthesis for two temperature ranges (2 to -2°C & 1 to -3°C), multiplied by (b) the distribution of anthesis around the predicted date of 50% anthesis.

Methods

The Catchment Analysis Tool (Beverly et al., 2005; Weeks et al., 2008) was used to investigate the frequency with which frost coincided with anthesis and the predicted impact on grain yields. The CAT crop model represents biomass accumulation based on extensively used contemporary models (Christy et al., 2013). It includes modules for plant phenology, crop growth and yield, together with dynamics of water and nitrogen in the crop and soil. CAT first simulates phenological progress, above-ground biomass accumulation and then partitioning to grain. Phenological development is driven by temperature and photoperiod. The CAT model was applied across the arable land in Victoria over a 50 year period (1965-2014). Model simulations were conducted on 1 km^2 grid cells of agricultural land within the 200-1000 mm annual rainfall region. For each year and grid cell within this region, the CAT model was triggered to sow wheat at the autumn break (defined by 25mm rain within 10 days) for a mid-season wheat cultivar, with a planting window from April 14 to June 30. To ensure that crops did not fail at planting, soil water was reset at sowing to the upper limit in the surface three layers (~30cm). For each year the number of days in which the minimum temperature was <2°C (or <1°C) was recorded, as well as the predicted yield with and without the frost damage. When frost damage was recorded the minimum temperature on the day that frost occurred was also recorded. There were a number of years in which the wheat crop failed, mainly in response to water stress. These years have been excluded from the analysis.

Results and Discussion

Using a sowing rule around an autumn break of 25mm the average planting date (over 50 years) across Victoria ranged from the 16 April through to 8 June, with the drier regions generally having a later autumn break and therefore planting data. The average anthesis date (50 years) ranged from the 9 August through to 20 November with the later anthesis dates located along the great divide due to colder average temperatures. Across the study region, the wheat crop failed to reach harvest an average of 0.3 years out of 50, with 84% of the study region having no crop failures. The highest frequency of crop failures was observed in the north west of the state where water-stress would be expected to cause premature terminal drought.

Frost around anthesis

Sowing a mid-season wheat cultivar on an autumn break resulted in a large variation in the frequency of frost events within a 14 day window around anthesis. Using a 2°C (Stevenson Screen) threshold frost coincided with anthesis 34 out of the 50 years on average, ranging from 0 to 49 years (Figure 2a). Across the study

region an average of 63% of years recorded more than 1 frost event in the 14 day anthesis window, ranging from none through 100% of years (Figure 2b). This high frequency of multiple frost events, suggests that future refinements of the crop model should consider how multiple frost events impact on yields.

When temperatures fall below the temperature threshold within the anthesis window, the frost module was triggered. For every year where a simulated crop was harvested, the predicted yield with and without the frost effect was recorded. Using a 2°C threshold an average reduction in yield of 7% was recorded across the study region (Figure 3a) with the greatest average losses of 14-22% observed in Western Victoria. If the threshold is dropped to 1°C (Figure 3b) there is a noticeable reduction in the yield losses predicted due to frost with an average of 3.2% across the study region.

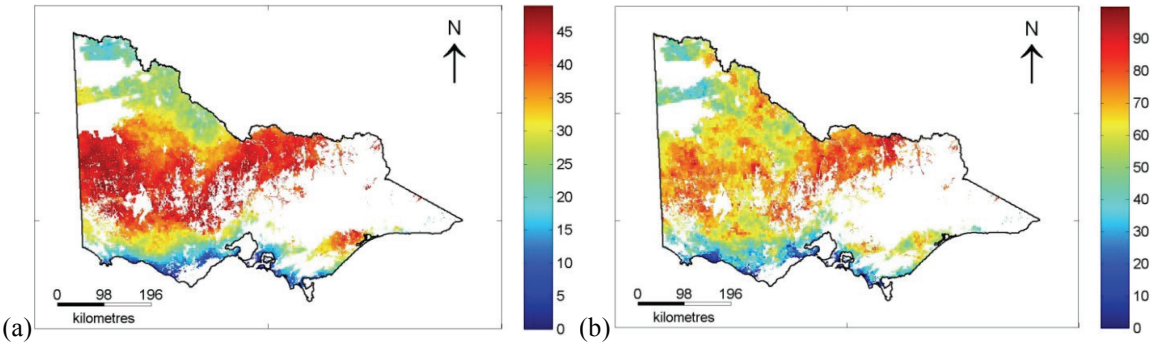

Figure 2. Average frost occurrence within a 14 day anthesis window based on a 2°C threshold for (a) the number of years out to 50 where frost was recorded, and (b) the percentage of years where multiple frost days were recorded.

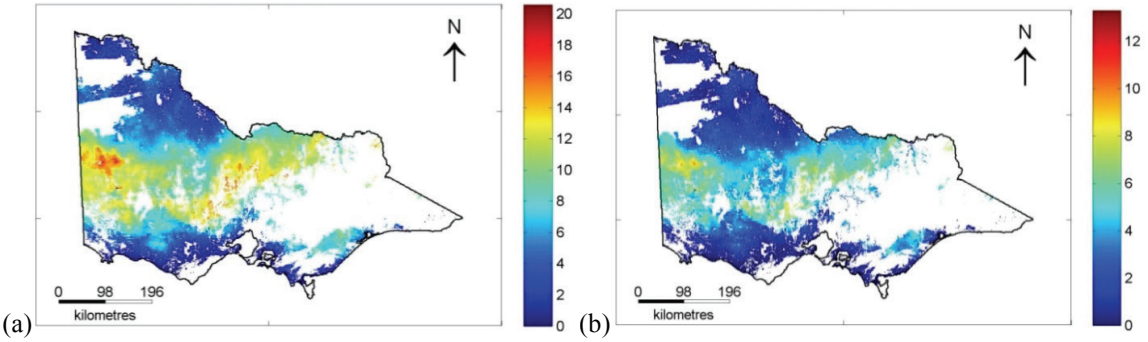

Figure 3. Average reduction in yield (%) due to frost damage (a) with a 2 to -2°C temperature range, and (b) with a 1 to -3°C temperature range.

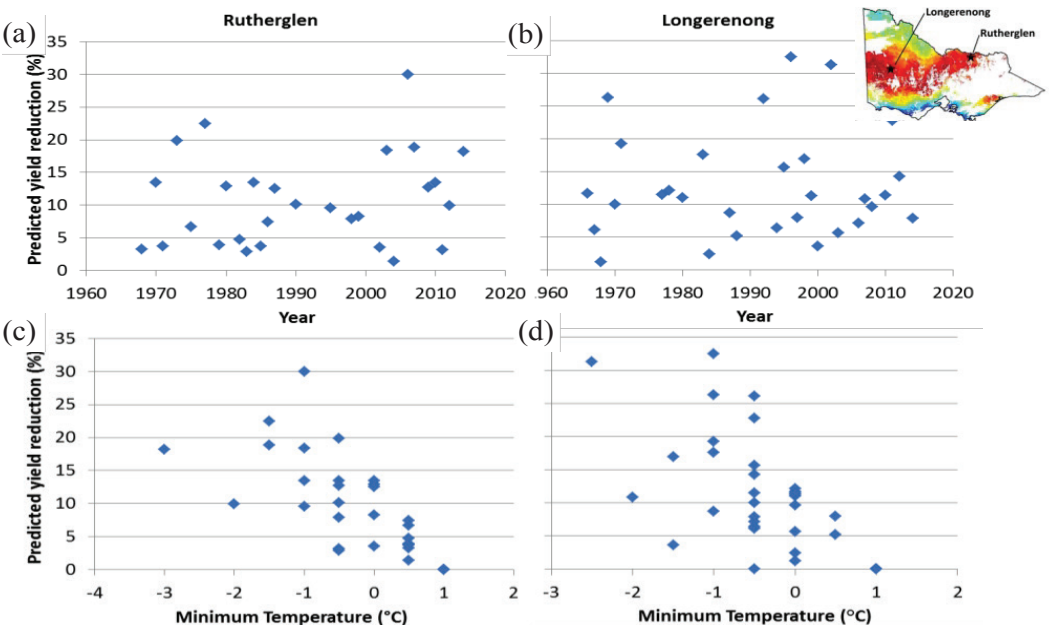

Figure 4. Annual reduction in yield (%) due to frost damage over time in (a) Rutherglen and (b) Longerenong with a 1 to -3°C temperature range. Annual reduction in yield (%) and the associated minimum temperature for (c) Rutherglen and (d) Longerenong.

The application of the CAT model spatially (1km^2 grids), provides an indication of the potential impacts of frost across the grain growing regions. However, frost is dependent on local minimum temperatures which can vary significantly from the nearest climate station, as well as across a paddock or farm. For the temporal response of the model we focused on two locations; Longerenong and Rutherglen. At Rutherglen with a 2 to -2°C temperature range frost was reported in 43 years resulting in an average of 13% reduction in yield. If the threshold is dropped by 1°C, then frost was recorded in 36 years and the average reduction in yield drops to 6%. Similarly for Longerenong with a 2 to -2°C temperature range frost was reported in 46 years resulting in an average of 17% reduction in yield. If the threshold is dropped by 1°C, then frost was recorded in 39 years and the average reduction in yield drops to 9%. There is significant temporal variation in the yield reduction recorded (Figure 4a, b) at both sites with a maximum reduction of 30-33% across the two sites. The minimum temperature resulting in frost losses varied, with damage recorded below the 1°C threshold (Figure 4c,d) highlighting the interaction within the model between timing and temperature. In this application, 90-100% yield losses were not observed, despite the potential for this to occur in the field, this suggests that further consideration is required of the criteria for maximum damage and the need to capture the impact of multiple frost events.

Conclusions and next steps

This paper presents a preliminary analysis of the application of the frost module (Figure 1) to mid-season wheat planted on an autumn break. The spatial response was consistent with expectations and the frequency of frost events coinciding with the anthesis period. Temporal data shows the variation in frost damage between years due to the multiplicative effect of minimum temperature and timing. The next step in developing this frost model is the validation of the response against experimental data. In further refining the model some key questions which still need to be addressed are (1) clarification of the distribution of frost sensitivity around anthesis and how the variation in anthesis within the crop affect whole crop impacts; (2) quantify the cumulative effect of multiple frost events over the anthesis window; and (3) consider how genetic differences in frost tolerance are incorporated within the frost module.

Acknowledgements

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Cold temperature under aerobic conditions increases spikelet sterility in rice (*Oryza sativa* L.)

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Abstract
Aerobic rice production (well-watered, non-flooded) has been proposed to improve water productivity. However, little research has been conducted on the effect aerobic conditions have on cold induced spikelet sterility. Two glasshouse experiments were conducted to examine the interaction between genotypes and water availability under cold temperatures. In each experiment, four genotypes were grown under aerobic and flooded conditions and half of all plants were exposed to cold temperatures (15/21°C) for a minimum of 14 days during the late booting stage. Water use was measured weekly until harvest and spikelet sterility was determined on the main stem panicle. Pollen number, anther size and stigma size were quantified. Under warm conditions, reductions in water use in aerobic conditions ranged from 58 to 85% compared to flooded (26L plant-1). When plants were exposed to cold temperatures, flooded conditions (34-48%) resulted in a significantly lower sterility than aerobic (70-80%). The genotypic effect in the cold treatment was significant in both experiments and sterility ranged between 36-78%. The lack of a significant interaction in both experiments indicates the mechanism for cold tolerance may be similar for flooded and aerobic conditions. Within the cold treatment, spikelet sterility was negatively correlated with the % viable pollen (r=-0.51*) and mean area of viable pollen (r=-0.60*) which reaffirms that the failure of the pollen grains is the leading cause for cold induced spikelet sterility at the late booting stage.

Key words
Aerobic, cold, booting stage, spikelet sterility, floral architecture

Introduction
Traditionally, rice has been grown under flooded conditions; however, increasing population and decreasing water availability has been applying pressure to improve water productivity. Recently aerobic production (well-watered, non-flooded) has been proposed to improved water productivity with field trials demonstrating an increase of 27-89% in water productivity (kg m^{-3}) in comparison to flooded production with no to small reductions in yield (Peng et al., 2006, Kato et al., 2009). A limitation to the adoption of aerobic production in temperate regions, such as the NSW Riverina, is cold induced sterility at the microspore stage where flooding with a 25cm 'water blanket' is recommended to act as a temperature buffer to protect the developing floral structures (Farrell et al., 2006). There is a current industry push to improve genotypic cold tolerance to reduce the depth of the water blanket with the eventual aim to introduce the opportunity to produce rice aerobically. These two glasshouse experiments examined the interaction of genotypes and water availability on intrinsic water use, cold induced sterility and its underlying physiological mechanisms.

Methods
Two temperature controlled glasshouse experiments were conducted at the University of Queensland, Brisbane, Queensland.

Experiment 1
Experiment 1 was conducted between March and August 2012. Reiziq (Australian cold susceptible lowland), Sherpa (Australian cold tolerant lowland), WAB 38 (African cold susceptible landrace) and Yunlu 29 (Chinese moderately cold tolerant upland) were grown in a completely randomised design with four levels of replication under aerobic and flooded conditions under control temperatures (21/28°C). At the late-booting stage, half were exposed to cold temperatures (15/21°C night/day) for 14 days and then returned to the control temperatures.

On 16 of March 2012, six seeds of were sown into four litre ANOVA® pots filled with 4.2kg of a Gatton black vertosol with 33.6g of Osmocote Exact 3-4M (16-9-12+ 2MgO + Trace elements). Pots designated

for the aerobic treatment had a 10cm petri dish placed approximately two-thirds of the way down to reduce root escape from the central hole in the ANOVA® pot. At 14 days after sowing (DAS), plants were thinned to two plants per pot and the water treatment imposed. A constant water table -22cm and +2cm from the soil surface was maintained for the aerobic and flooded treatments respectively via a valve. The valve for the aerobic treatment was within a 'pot in bucket system' placed below the pot and water was supplied to the pot via a capillary mat as described by Hunter et al. (2012) . The supply of water for each pot was from an individual five litre graduated bottle which enabled the measurement of the plant's water use (WU) from 14DAS to harvest. In the flooded treatment, the valve was placed on the soil surface. Pots were thinned to one plant at 42DAS and plant water use before then was assumed to be half of the measurement from the graduated bottle. In both treatments, the top and sides of the pots were covered with insulation to prevent excessive heating and evaporation. When the auricle of the flag leaf and penultimate leaf of the main stem intersected (AD = 0±2cm), half of all plants were transferred into the cold room (15/21°C) for 14 days before being returned to the warm room. WU was measured weekly. The number of filled and unfilled spikelets on the main panicle was determined at physiological maturity for determination of spikelet sterility.

Experiment 2

Experiment 2 was completed over 2012-2013. Lijiangheigu (Chinese cold tolerant landrace), M205 (USA lowland), and Australian varieties Reiziq and Sherpa were grown and exposed to cold temperature treatments as described for experiment 1. On the 7th of August 2012, six seeds of were sown into four litre ANOVA pots filled with 2100g ± 50g of composted pine bark with 20g of basacote 3M (16-8-12+ 2Mg+ 5S + Trace elements) and grown as experiment 1 with the media's moisture content in aerobic conditions maintained around field capacity. Water use and spikelet sterility were measured as per experiment 1.

The original settings for the cold temperature glasshouse (15/21°C night/day) based on Experiment 1 led to an elevated day temperature of 25°C due to increasing ambient temperature. To compensate the settings were adjusted 12 days after the initial transfer of the first replicates which led to cold glasshouse temperatures of 11/21°C. The exposure to the cold temperatures was also extended from 14 to 18 days to ensure all replicates received a minimum of five days in the lower temperatures.

Sampling for pollen characteristics occurred on the main stem one to two days after heading (only the cold treatment reported). Spikelets were sampled from the third, fourth and fifth spikelets on the first, second and third lower primary branches (Gunawardena et al., 2003). If the panicle was not fully extruded, the sheath was peeled back to permit sampling. The spikelets were stored in a 50% ethanol solution at 4°C for up to 12 weeks before processing. Three spikelets were dissected to expose the anther and stigma and an image was captured for later image analysis (Olympus SZX10®; Lumenera's Infinity1-1M®). Two anthers from each of three spikelets were then stained with an Iodine Potassium Iodide solution (IKI; 5g I2 and 20g KI in 1L of water). The anthers were macerated individually using a splinter probe and the pollen distributed on a slide for image capture under a stereo microscope. Analysis of anthers, pollen and stigma style was undertaken with freeware program ImageJ®. Anther length was measured from the apex of the thecea to the base of the long locule, width was measured at the widest point and area was determined via the number of pixels. Stigma and style traits were calculated on the same basis of the anthers measurements with length being from the base of the style to the apex of the longest stigma, the widest point across the stigmas and area being calculated with pixels. Pollen which contained carbohydrate stained black with IKI is a proxy for pollen viability (Figure 1). Pollen which lacked carbohydrates appeared as transparent yellow and were classed as unviable pollen. Pollen with partial staining was also present, which was clearly different from viable pollen, was also classed as unviable pollen. Analysis with ImageJ® allowed for the quantification of total pollen number per anther, viable pollen number (stained black) per anther, % viable pollen (viable pollen number / total pollen number) and mean area of the viable pollen. The latter was examined as it has been identified as a key determinant in pollen fertility (r=0.89**) in *Mimulus guttatus* with the diameter of unviable pollen being approximately 13µm smaller than viable pollen (Kelly et al., 2002).

Data Analysis

Analysis of Variance (ANOVA) was completed using Genstat 17®. Two-way factorial analysis was partaken separately between cold and warm temperatures as the assumption of homogenous variance was not valid using three-way ANOVA. The variable temperature in the cold treatment in Experiment 2, led to the use

of analysis of covariance using the mean minimum temperature of time in the cold room as the covariate (Farrell et al., 2006). The effect of the temperature was compared using a student's t-test of non-homogenous variance.

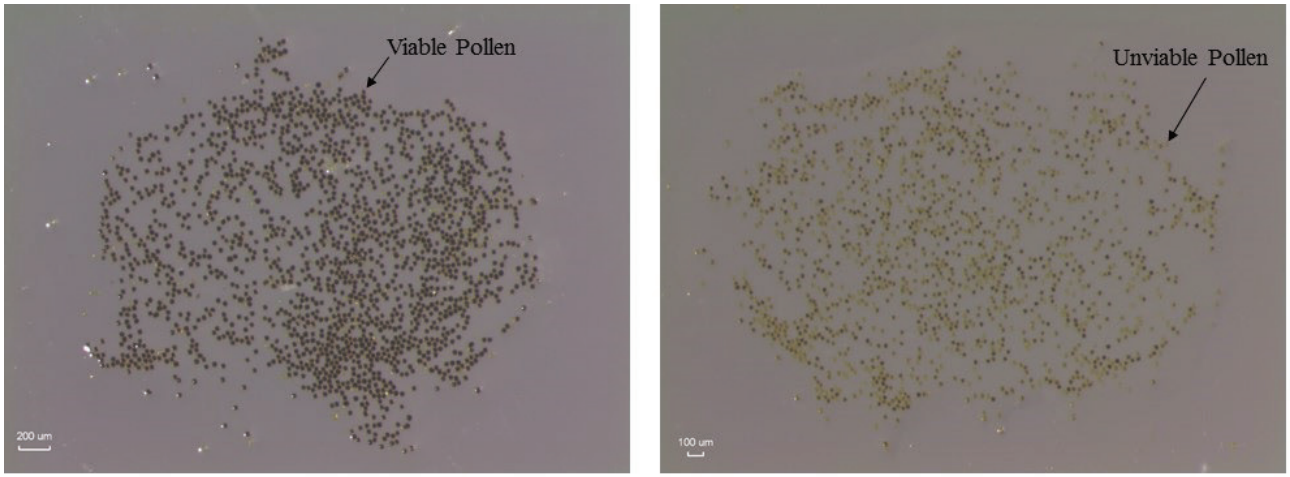

Figure 1: An example of M205 pollen development under warm (a) and cold (b) temperatures under aerobic conditions.

Results and discussion

A highly significant ($p<0.01$) effect of the water regime (WR) existed for cumulative water use under warm temperatures in both experiments with the flooded (24.5-25.7L) utilising more than aerobic conditions (3.8-10.4L). Aerobic conditions in experiment 1 (3.8 L) had a lower level of water utilisation than experiment 2 (10.4L), which is indicative of a lower water availability in the black soil.

In experiment 1, spikelet sterility under aerobic (45%) conditions was significantly ($p<0.01$) higher than the flooded (10%) under warm temperatures (Table 1). A highly significant ($p<0.01$) WR by genotype interaction effect existed, with genotypes not being significantly different from each other (5-15%) in flooded conditions. Under aerobic conditions, Sherpa (9%) had a significantly ($p<0.05$) lower sterility than WAB38 (80) and Reiziq (65%) in experiment 1. However, in experiment 2 there was no significant genotype effect, WR or genotype by WR interaction in the warm treatment (Aerobic (A) 16; Flooded (F) 15%). A highly significant ($p<0.01$) temperature effect occurred in both experiments with warm temperatures (15-27%) having a lower spikelet sterility than the cold (57-59%). Within the cold temperature, spikelet sterility was significantly ($p<0.01$) higher in aerobic conditions (70-80%) than the flooded (34-48%). In both experiments, a significant ($p<0.05$) genotypic effect occurred with Sherpa (36%) having a lower spikelet sterility than Reiziq (58%) and WAB38 (78%) in experiment 1. In experiment 2, Lijiangheigu (46%) had a significantly ($p<0.05$) lower spikelet sterility than M205 (71%). The lack of an interaction suggests that there is a net impact of a reduction in water availability on spikelet sterility which increases with reducing availability. In experiment 2, there was a significant ($p<0.05$) effect of the temperature covariate.

Within the cold treatment (experiment 2), there was a significant ($p<0.05$) effect of the water regime on total pollen number (A 1379; F 1154 pollen grains per anther), viable pollen number (A 700; F 995 viable pollen grains per anther), % viable pollen (A 49; F 86%) and mean area of viable pollen (A 576; F 856 um^2). With the exception of total pollen number, aerobic conditions had a negative impact on the pollen characteristics in comparison to the flooded. No significant effects occurred in anther or stigma style dimensions. Spikelet sterility was significantly ($p<0.05$) and negatively correlated with the % viable pollen ($r=-0.51^*$) and mean area of viable pollen per anther ($r=-0.60^*$) which reaffirms that failure of the pollen grains are the leading cause of cold induced sterility (Farrell et al., 2006, Gunawardena et al., 2003, etc). It also suggests that the ability for the available pollen to remain viable (% viable pollen and mean area) is important for cold tolerance. Spikelet sterility is commonly reported to have a negative correlation with viable pollen number per anther and anther length (Gunawardena et al., 2003, Farrell et al., 2006), this did not occur in this study nor was there any relationship with dimensions of the style and stigma. Farrell et al. (2006) also reported that the correlation was not significant in all experiments that confirms the conclusion that there are various mechanisms leading to spikelet sterility.

Table 1: Spikelet sterility (%) under warm and cold conditions in Experiment 1 and 2 (Experiment 2 adjusted for the temperature covariate).

Experiment 1							Experiment 2		
	Warm			Cold				Warm	Cold
	Aerobic	Flooded	Mean	Aerobic	Flooded	Mean			
Reiziq	65	5	35	87	31	58	Lijiangheigu	18	46
Sherpa	9	12	11	57	16	36	M205	19	71
WAB38	80	15	47	99	57	78	Reiziq	18	59
Yunlu 29	24	8	16	80	31	55	Sherpa	6	59
WR Mean	45	10		80	34		Aerobic	16	70
							Flooded	15	48
Temperature Mean	27			57			Mean	15	59
LSD 5%							LSD 5%		
Genotype			22**			18**		ns	11*
WR			16**			13**		ns	14**
Genotype x WR			31**			ns		ns	ns
Temperature			11**					13**	

Conclusion

Aerobic conditions reduced the water used by rice plants by 58-85% compared to flooded conditions. When water availability was maintained at field capacity, there was no detrimental impact on spikelet sterility under warm temperatures. However, in cold temperatures the reduction in water availability led to a net increase in spikelet sterility (97-140%). The lack of interaction for spikelet sterility in experiment 1 suggest that genotypes with adaption to lower water availability does not decrease the level of sterility in comparison to lowland genotypes when exposed to cold temperatures. To confirm the hypothesis, an experiment should be conducted with a larger range of genotypes with adaption to low water availability. Experiment 2 reaffirmed that failure of the pollen grains is the leading cause for spikelet sterility, however, the correlation with % viable pollen and mean viable pollen diameter rather than viable pollen per anther indicates that there are multiple pathways in which spikelet sterility occurs. Further elucidation of the underlying physiological mechanisms is required to improve cold tolerance under flooded and aerobic conditions.

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Use of chemical protective products to change the ability of wheat to tolerate frost

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Abstract
Frost is a large issue limiting cereal production across the Australian wheat-belt. Successful frost risk management requires an integrated approach involving many aspects of the farming system, such as sowing time, crop/cultivar selection, stubble management and plant nutrition. A number of commercial chemical products have become available in recent times that reputedly protect crops from frost damage. During 2014 at Mintaro, South Australia, four protectant products (anti-transpirant and biochemical products) were applied and one plant growth regulator, trinexapac-ethyl, to wheat plots sown at seven weekly intervals to assess their potential to alleviate frost damage. Several frost events occurred during the growing season. The degree of frost damage varied across each time of sowing corresponding to frost events at susceptible stages of plant development. Of the chemical protectants tested, none provided any significant reduction in frost induced sterility or gains in yield compared with the untreated control. However, trinexapac-ethyl increased the sensitivity of wheat to frost. Average frost induced sterility increased from 42% of the untreated control to 51% when applied during stem elongation. This difference in sterility was also reflected in grain yield as the same treatment was 8% lower yielding than untreated plots. Preliminary results of this study suggested none of the tested chemical anti-transpirant or biochemical products offered any significant improvement in frost tolerance.

Key words
Frost, chemical protection, wheat

Introduction
Frost causes major economic losses to the Australian grains industry through crop yield reductions and grain quality downgrading. Estimated costs of direct losses attributed to frost are approximately $63M annually in wheat and barley. While indirect costs from losses caused by delayed sowing to avoid frost are almost up to $300M per year. Many factors in modern cropping systems have attributed to making them more prone to frost damage. These include factors such as minimum tillage, stubble retention and timeliness of seeding. These higher yield potential crops combined with increased incidence and severity of frosts (Zheng et al. 2015) has caused modern farming systems to be more susceptible to losses from frost when they occur.

Past agronomic research has identified that management practices can influence the canopy temperature causing changes in frost damage. Clay delving, removing stubble and land rolling have all shown varying levels of success in increasing canopy temperature (Rebbeck et al. 2007). Practices such as clay delving are only suitable in specific soil types. Other practices used to manipulate the crop canopy have shown evidence to suggest frost damage may be reduced. These practices include, blending crop varieties, cross-sowing, increasing row spacing, lower seeding rate and delayed sowing (Rebbeck et al. 2007). Another agronomic approach to investigate in frost risk management is the use of chemical frost protectants. A number of commercially available chemical spray-on products are currently marketed to provide frost protection for various crops, mainly focusing on horticultural crops such as grapevines, tomatoes and fruit trees. Such products include anti-transpirants, biochemical compounds and plant growth regulators. The purpose of this this study was to evaluate the effectiveness of these products to mitigate frost severity in wheat.

Methods
A field experiment was undertaken at Mintaro, South Australia during 2014 to investigate the use of various chemical frost/cold stress protectants in their ability to alleviate frost damage symptoms in wheat. Wheat (cv. Mace and Scout) was sown at an appropriate seeding rate based on seed weight to reach a target density of 200 plants/m^2. Plots were 5m by 1.4m and sown using knife point and press wheels with 23cm row

spacing. There were 20 chemical treatments including an untreated control applied to each wheat variety. This included five different chemical products applied at various different crop growth stages (Table 1). Each chemical was applied using a hand-held, gas pressurized boom with a water volume rate of 100L/ha. Each treatment was replicated three times in a completely randomized block design. The experiment was sown seven times at weekly intervals beginning on the 15th of April. The purpose of this was to increase the duration of the wheat flowering window to increase the likelihood of a frost event occurring during this period of susceptibility.

Table 1. List of chemical treatments applied at various rates and application times.

Treatment No.	Treatment	Timing (Zadok growth stage)	Product rate (g.a.i/ha)
1	Control		
2	Dicarboxylic acids	Z32	20
3	Dicarboxylic acids	Z51/55	20
4	Dicarboxylic acids	Z61/65	20
5	Dicarboxylic acids	Z32 + Z51/55	20 + 20
6	Terpene polymer blend	Z32	275
7	Terpene polymer blend	Z51/55	275
8	Terpene polymer blend	Z61/65	275
9	Terpene polymer blend	Z32 + Z51/55	275 + 275
10	Di-1-p-menthene	Z32	2260
11	Di-1-p-menthene	Z51/55	2260
12	Di-1-p-menthene	Z61/65	2260
13	Di-1-p-menthene	Z32 + Z51/55	2260 + 2260
14	Experimental biochemical product	Z32	125
15	Experimental biochemical product	Z51/55	125
16	Experimental biochemical product	Z61/65	125
17	Experimental biochemical product	Z32 + Z51/55	125
18	Trinexapac-ethyl	Z30	100
19	Trinexapac-ethyl	Z33	100
20	Trinexapac-ethyl	Z39	100

Climate data was recorded at the experiment location, with the temperature measured at canopy height to identify the severity of the frost events. Crop growth stages were scored at weekly intervals from late stem elongation. Prior to maturity samples comprising of 30 heads were collected from each plot and all outer florets of each head were counted and identified as sterile or fertile. From this observation the percentage of sterile florets or frost induced sterility (FIS) was calculated for each head sample. At maturity, plots were harvested with a small plot harvester to determine grain yield.

All statistical analyses were completed using the GENSTAT statistical analysis software, using REML multiple experiment. Each sowing time was treated as a separate experiment and only those sowing times where frost events occurred during flowering or early grain fill were included in the analysis.

Results

The experiment location was affected by a large number of frost events during the 2014 growing season. In the months from August to October, there were 35 days with minimum temperatures below 0°C at Stevenson screen height (1.2m above ground level). The lowest temperature recorded was -5.7°C. The first two sowing times were removed from the analysis due to severe stem frost damage before many of the chemical treatments were applied.

Of the chemical products applied, none provided any significant gains in frost tolerance. Untreated control wheat plots averaged 42% floret sterility (Figure 1). The chemical protectants were not found to have any significant effect on sterility at any of the application times used in this study. Anti-transpirants, such as di-1-p-menthene and terpene treatments were included in the study as they may provide a physical barrier to reduce freezing damage to the plant. This study showed that they provided no useful effect to reduce the degree of frost damage in wheat. Similarly, the dicarboxylic acid product had no impact on grain sterility caused by

frost. The plant growth regulator (PGR), Trinexapac-ethyl significantly increased the levels of floret sterility at all application times. The level of damage was consistently 50-51% sterility with applications ranging from early stem elongation (Zadoks 30) to flag leaf emergence (Zadoks 39). It is unclear why this increased level of sterility occurred. The PGR treatments delayed maturity by 1-3 days depending on sowing time, but due to the frequent nature of the frost events during the flowering period this small change in flowering time is unlikely to have influenced the level of frost damage. Differences in plant biomass were also negligible (data not shown), especially at the later sowing times. Trinexapac-ethyl may have affected the level of water soluble carbohydrates within the wheat plant, which may have influenced the level of frost sensitivity.

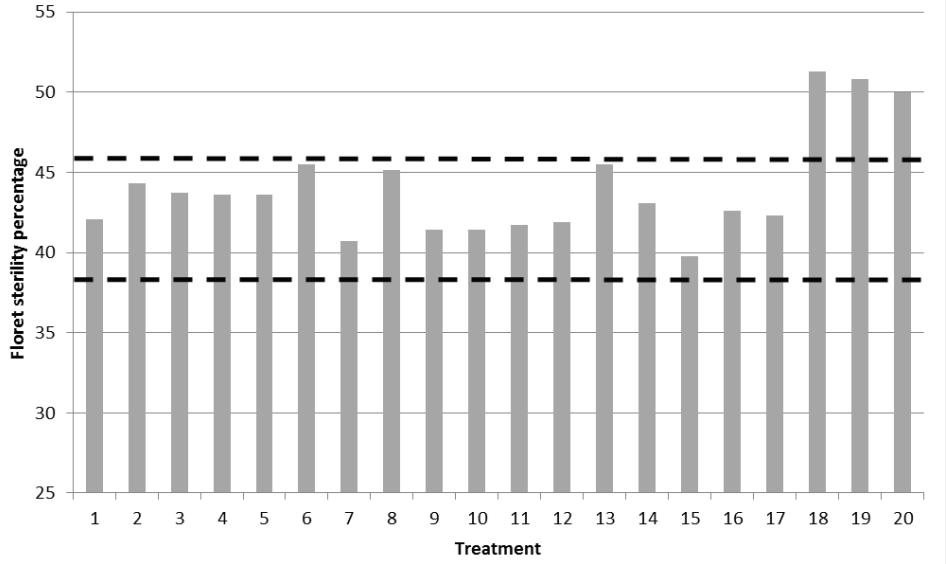

Figure 1. Effect of different chemical protectant treatments (Table 1) on floret sterility following frost events during reproductive development in wheat. Dashed lines represent significant difference to control (treatment 1) at *P*<0.05 level of significance (LSD = 3%).

The differences in grain yield were strongly correlated to the observed floret sterility from each of the chemical treatments. None of the tested chemical protectants provided any improvements in grain yield as was found with floret sterility. Untreated control wheat plots yielded on average 3027 kg/ha. Some protectant products trended to have slightly higher yields, but were not significantly different to the control (Figure 2). This result may have been influenced by the multiple severe frost events encountered during the season, where the extreme minimum temperatures and long duration below 0°C was too severe to enable the applied products to provide any benefit. The negative impact of the PGR, Trinexapac-ethyl on increased floret sterility was also reflected in grain yield. The 3-node (Zadoks 33) and flag leaf emergence (Zadoks 39) applications were significantly less that the control, with up to 8% lower grain yields (Figure 2).

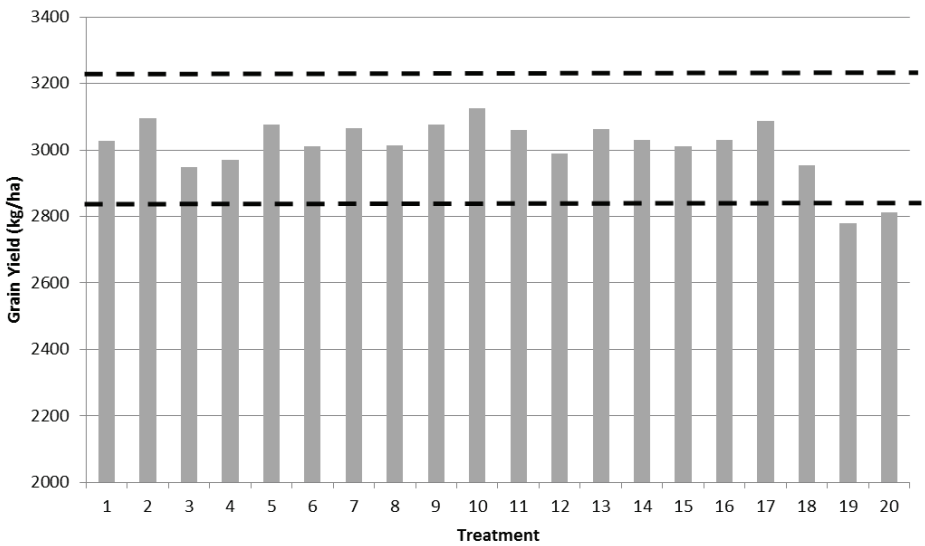

Figure 2. Effect of different chemical protectant treatments (Table 1) on grain yield following frost events during reproductive development in wheat. Dashed lines represent significant difference to control (treatment 1) at *P*<0.05 level of significance (LSD = 195kg/ha)

Conclusion

The ability of wheat to tolerate frost conditions was not improved by any of the products assessed in this study. The use of Trinexapac-ethyl increased the level of frost sensitivity, through higher floret sterility and consequently reduced grain yields. The reason for this change in frost susceptibility is unclear, but it is unlikely to be due to phenology changes that reduced exposure to frost. The severe frost conditions encountered during this study may have limited any potential effectiveness the chemical products may have provided. Therefore further evaluation of these chemical products is warranted. The increasing use of plant growth regulators to manage crop canopies makes further characterisation of the interaction with frost damage of significant interest.

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Potential new cultivars of phalaris for the medium rainfall (450-550 mm) mixed farming zone in southern New South Wales

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Abstract
Pastures based on perennials offer production and sustainability benefits in the mixed farming zone of southern NSW. Phalaris is commonly used in this zone but much less in the drier (450-550 mm long term average rainfall, LTA) western portion. Five phalaris populations developed in high moisture stress environments were compared with cultivars recommended for this zone (Atlas PG, Sirolan) and other cultivars on a clay loam at Yanco (LTA 430 mm) from 2008-13 and on a red-brown sandy loam at Yanco and Beckom (LTA 460 mm) from 2009-13. Rainfall was well below average in 2008 and 2009 and well above average in 2010 and 2011. High moisture stress in spring 2012 to autumn 2013 severely reduced basal frequency at all sites. One population (NorthernR) was higher in basal frequency than one or both of Atlas PG and Sirolan at all sites by 2013. Annual phalaris production of two populations, NorthernR and P × C, was usually higher at all sites than Atlas PG and other cultivars except Sirolan. Three populations yielded more than Sirolan at the Yanco 2008 site but Sirolan ranked high at the 2009-sown sites. Across all sites, NorthernR and P × C had the highest cumulative yield but Sirolan was equal to these averaged across the sites sown in 2009. Sirolan should remain a recommended cultivar for this zone. A cultivar with higher summer dormancy than Sirolan for lower rainfall areas will be selected by 2018 to replace Atlas PG.

Key words
Phalaris aquatica L., drought tolerance, harding grass, perennial grasses, summer dormancy

Introduction
Farms in the mixed farming zone of southern New South Wales (NSW) typically support crops grown in phased rotation with annual and perennial pastures. Deep-rooted perennials in the pasture phase have the potential for sustainability benefits by reducing dryland salinity and soil acidification compared with annual based pastures (Hayes et al. 2010). Perennial-based pasture also offers livestock production benefits compared with annual pasture because of the potential for out-of-season growth, higher stocking rates and reduced supplementary feeding (Dear et al 2010). Lucerne is the dominant perennial in the mixed farming zone used on 84% of farms (Dear et al. 2010) due to its drought-hardiness, N fixation and out-of-season growth but is more sensitive to acid soils and heavy grazing and has lower ground cover compared with perennial grasses such as phalaris and cocksfoot (Hayes et al. 2010).

Phalaris is commonly used in the mixed farming zone of southern NSW (48% of farms; Dear et al. 2010) but unlike lucerne is more common (64% of farms) in the high rainfall east of the region (550-700 mm LTA) than in the lower rainfall west (450-550 mm LTA; 35% of farms). Cultivars with higher summer dormancy are recommended for areas with long dry summers where moisture from summer storms does not last until autumn (Oram and Freebairn 1984). This role is currently filled by Atlas PG but this cultivar has not always performed as well as older cultivars (Boschma and Culvenor 2008; Hayes et al. 2012). Sirolan, an older cultivar recommended also for this zone, has low summer dormancy which allows it to respond to summer rainfall and compete more actively with weeds but it is less persistent than summer dormant cultivars in more extreme dry environments (Oram and Freebairn 1984). Culvenor and Boschma (2005) identified relatively early-flowering and summer-dormant germplasm that survived better than Atlas PG under high moisture stress and grazing on the North-West Slopes of NSW. Five new populations were bred by CSIRO which survived better than Atlas PG on the North-West Slopes (Boschma and Culvenor 2008) and these have been tested in dry marginal areas for temperate grasses in south-eastern Australia (Culvenor et al. 2012). The new populations performed relatively well at sites in southern NSW but it was not clear which population should be released as a cultivar. This paper provides further data on the performance of the new populations

at two localities on the dry margin of the medium rainfall mixed farming zone (LTA 450-550 mm) as part of a broader study of adaptation of phalaris to dry environments. Culvenor et al. (2012) reported early results from the Yanco 2008 site which showed that four of the populations established at higher density than Sirolan and Atlas PG following early drought, and that three populations had higher herbage mass than these cultivars.

Methods

Five new phalaris populations, Northern Retainer, Sirocco Retainer, 19305 Retainer (hereafter called NorthernR, SiroccoR, 19305R), P × C and Tam PWA, and the commercial cultivars Atlas PG, Sirolan, Holdfast, Landmaster, Australia and Australian II were grown among a wide range of phalaris germplasm (30 entries total) on two sites at the Yanco Agricultural Institute (430 mm LTA, 34.603 S, 146.410 E) and one site at Beckom (460 mm LTA, 34.267 S, 146.996 E). The first four populations are of the higher summer dormancy type like Atlas PG but are earlier flowering. The first site at Yanco was on a red-brown clay loam soil (pH in CaCl2 4.8) and was sown in 2008. The other two sites were sown in 2009 on a red-brown sandy clay loam at Yanco (pH 5.2) and on a red-brown sandy loam at Beckom (460 mm LTA, pH 4.8). The first Yanco site was sown on 1 July 2008 and the second site on 28 May 2009. The Beckom site was sown on 18 May 2009. Plot size was 4 m × 1.2 m at Yanco and 5 m × 0.9 m at Beckom. All sites were arranged in row-column designs with four replicates. Sowing rate was 2.2 kg/ha of viable seed. DAP (18%N, 20%P, 1.6%S) at 125 kg/ha was incorporated before sowing at Yanco and Pasture Starter (7%N, 14%P, 9%S) at 180 kg/ha at Beckom. The Yanco 2008 site was irrigated in September 2008 and the Yanco 2009 site in August 2009 due to severe moisture stress under well below average rainfall (Table 1). Mainly broadleaf weeds were controlled by spraying with 4 L/ha of a 340 g/L MCPA plus 80 g/L Dicamba mix, wiping concentrated glyphosate and hand weeding. Fertilisers were applied annually as 125 kg/ha of single superphosphate (9% P) plus 100 kg/ha of Nitram (35% N) up to 2011 and 90 kg/ha of Granulock 15 (15% N, 12% P) after 2011 at Yanco. At Beckom, the same rate of super plus Nitram as at Yanco was applied in 2011 supplemented with 50 kg/ha of urea (46% N), 90 kg/ha of urea in 2012, 100 kg/ha of Granulock 15 plus 50 kg/ha of urea in 2012 and 105 kg/ha of Granulock 15 in 2013. Basal frequency was measured each winter in two 1.1 m2 fixed quadrats per plot at Yanco and two 0.9 m2 fixed quadrats at Beckom by counting the number of 0.1 × 0.1 m cells containing live phalaris base, and calibrated visual assessments of phalaris herbage mass were taken 3-4 times during the growing season at Yanco and seasonally at Beckom. Yanco sites were grazed after each assessment and Beckom grazed or mown depending upon availability of animals. In 2013, Yanco 2008 was assessed in June only, Yanco 2009 three times and Beckom twice. Spatial analyses of basal frequency and annual total phalaris herbage mass were performed using REML in Genstat for Windows 14th Edn. Across site analyses of cumulative phalaris herbage mass from 2010-13 were also performed with entry as a fixed effect and site, site.line and row and column as random effects.

Table 1. Annual and long-term average (LTA) rainfall (mm)

Locality	LTA	2008	2009	2010	2011	2012	2013
Yanco	430	343	289	548	591	575	370
Beckom	460	-	330	594	632	534	423

Results

Rainfall was well below average in 2008 and 2009 but well above average from 2010-12 (Table 1). Over half of the 2012 rainfall fell by early March and the period spring 2012 to autumn 2013 was a severely dry period that caused a decline in basal frequency at all sites (Table 2). At the Yanco 2008 site, all of the new populations except TamPWA had higher frequency than the commercial cultivars in the second year (2009; Culvenor et al. 2012) and were still higher in basal frequency in 2012 than all cultivars except Atlas PG (Table 2). Only NorthernR had greater frequency than Atlas PG after the severe 2013/14 summer. At the Yanco 2009 site, NorthernR was higher in frequency than Atlas PG and Sirolan in 2012, and 19305R and TamPWA were also higher than Atlas PG (Table 2). By 2013, basal frequency had declined severely but NorthernR, SiroccoR and P × C were higher than some less summer dormant entries such as Sirolan and Holdfast. At Beckom, establishment frequencies were generally higher than at Yanco and reached very high levels by 2012 under high rainfall. In 2013, NorthernR was the only new population with higher basal frequency than the commercial cultivars. Australian and Australian II persisted poorly at all sites. The P × C population declined markedly in the final summer at Beckom.

Table 2. Basal frequency in the year of sowing and the last 2 years of the study at 3 sites

Entry	Yanco 2008			Yanco 2009			Beckom 2009		
	2008	*2012*	*2013*	*2009*	*2012*	*2013*	*2009*	*2012*	*2013*
NorthernR	20	33	25	40	35	18	53	69	37
SiroccoR	14	27	14	35	22	16	47	64	29
19305R	19	32	13	33	25	14	48	74	30
P × C	17	34	19	43	24	17	47	71	19
TamPWA	17	22	9	31	26	10	50	74	27
Atlas PG	17	24	11	36	15	10	53	64	24
Sirolan	18	16	11	42	22	8	61	62	27
Holdfast	18	14	5	39	15	7	53	62	27
Landmaster	24	11	10	35	22	10	63	61	16
Australian	28	8	7	43	18	5	66	54	19
Australian II	21	5	3	34	13	2	54	55	13
lsd (P=0.05)		12			10			12	

Consistent with basal frequency differences, phalaris herbage production at the Yanco 2008 site was higher for P × C, NorthernR and 19305R than for Atlas PG, Sirolan and other cultivars in 2010 (Table 3). The same relative differences remained in 2011 and 2012 but only NorthernR was significantly higher (P<0.05) than the commercial cultivars in 2011 and none of the new populations were significantly higher in 2012. NorthernR and P × C were higher in herbage mass in 2013. Over the years 2010-13, P × C produced the highest cumulative DM but not significantly higher than NorthernR and 19305R. All three were higher than SiroccoR, TamPWA and the commercial cultivars.

Table 3. Annual phalaris herbage production (t DM/ha) from 2010 to 2013 (10-13) at 3 sites and the cumulative total production for these years (Σ10-13)

Entry	Yanco 2008					Yanco 2009					Beckom 2009				
	10	*11*	*12*	*13*[a]	$\Sigma_{10\text{-}13}$	*10*	*11*	*12*	*13*[b]	$\Sigma_{10\text{-}13}$	*10*	*11*	*12*	*13*[c]	$\Sigma_{10\text{-}13}$
NorthernR	5.5	3.0	2.2	0.29	10.9	3.2	2.8	2.8	1.8	10.6	9.0	5.7	5.7	1.3	21.8
SiroccoR	4.0	1.9	1.3	0.14	7.1	2.5	1.8	1.8	1.4	7.1	8.8	5.6	6.4	1.4	22.2
19305R	6.0	2.7	1.8	0.13	10.8	1.6	1.8	2.5	1.6	7.7	8.4	5.9	6.2	1.2	21.6
P × C	6.6	2.6	2.2	0.21	12.0	3.6	2.0	2.4	1.7	9.7	9.3	6.0	5.9	0.8	22.0
TamPWA	3.9	1.7	1.0	0.09	7.0	2.2	1.7	2.0	0.9	6.9	7.8	5.4	5.0	0.7	18.7
Atlas PG	3.5	1.8	1.3	0.06	6.6	1.7	1.5	1.7	0.9	6.1	8.2	5.3	4.9	0.4	18.8
Sirolan	2.7	1.6	1.3	0.05	5.7	2.6	3.4	3.3	1.4	10.4	9.1	6.3	6.2	0.9	22.4
Holdfast	2.3	1.3	1.1	0.07	4.7	1.7	1.6	1.5	0.7	5.9	9.1	6.3	5.7	0.5	21.5
Landmaster	2.1	1.0	0.9	0.12	4.0	1.7	2.1	2.2	1.0	7.0	8.5	5.9	4.9	0.4	19.7
Australian	0.8	0.5	0.6	0.03	2.2	0.7	1.3	1.3	0.4	3.4	5.6	4.3	3.5	0.1	13.5
Australian II	0.8	0.3	0.4	0.00	1.7	1.0	1.5	1.4	0.1	3.9	6.1	4.1	3.6	0.1	13.7
lsd (P=0.05)		1.17		0.13	3.7		1.49			3.9		0.75			2.0

[a] Assessed late June [b] Assessed June, August, October [c] Assessed June, August

P × C and NorthernR were also more productive than the commercial cultivars except Sirolan at the Yanco 2009 site in the high rainfall year 2010, and higher than the 19305R population (Table 3). Sirolan was the most productive entry in 2011 and 2012 when rainfall was also above average but not significantly (P<0.05) higher than NorthernR, P × C and Landmaster in both years and also 19305R and TamPWA in 2012. After the severe final summer, few significant differences were observed but the new populations (except TamPWA) and Sirolan formed a generally higher yielding group (Table 3). Over the years 2010-13, NorthernR, Sirolan and P × C had the highest cumulative production at the Yanco 2009 site.

The Beckom site had lower error in DM production than the Yanco sites due to a more even establishment. P × C, Sirolan, Holdfast and NorthernR yielded higher than Atlas PG in 2010 but the TamPWA population was relatively low yielding (Table 3). Sirolan and Holdfast were also highest yielding in 2011 but not different

from the new populations except TamPWA. The new populations except TamPWA yielded higher than Atlas PG in 2012 but were similar in production to Sirolan and Holdfast. Three of these populations, SiroccoR, NorthernR and 19305R yielded higher than Atlas PG in 2013 but were not significantly higher than Sirolan. P × C did not differ from Atlas PG due to its decline in persistence in the final summer. Compared with Yanco, the SiroccoR population was more prominent in the later years at Beckom. Over the years 2010-13, the new populations (except TamPWA), Sirolan and Holdfast did not differ in cumulative production (Table 3).

Notwithstanding a significant entry × site interaction ($P<0.01$), rankings in the analysis of cumulative herbage production from 2010-13 across all three sites showed that NorthernR (14.7 t/ha) and P × C (14.6 t/ha) were higher than 19305R (13.5 t/ha), Sirolan (12.9 t/ha) and SiroccoR (12.4 t/ha). All were considerably higher than Atlas PG (9.7 t/ha) (data not shown). Restricting the analyses to the sites in 2009 to remove the effect of establishment differences at the Yanco 2008 site, Sirolan (16.5 t/ha), NorthernR (16.3 t/ha) and P × C (15.9 t/ha) were higher than SiroccoR (14.8 t/ha) and 19305R (14.4 t/ha) and higher than Atlas PG (12.0 t/ha), Landmaster (13.5 t/ha) and Holdfast (13.1 t/ha).

Conclusion

NorthernR and P × C were the most productive of the new populations over 4 years which is the typical length of a pasture phase in this zone. This was in part influenced by their relatively good establishment, along with 19305R, at Yanco in 2008 possibly due to earlier development. Under more even establishment and higher rainfall from the second year at 2009 sites, Sirolan was at least the equal in production of the four new higher summer dormancy populations which did not differ from each other. Sirolan should remain recommended for this zone for its high production and ability to respond to summer rains. There was some evidence that NorthernR is more persistent than other entries. A cultivar with higher summer dormancy to replace Atlas PG will be selected by 2018.

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Plantain and chicory could potentially complement the perennial ryegrass dominant dairy feedbase

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Abstract
A modelling study was undertaken to identify if pasture mixtures or monocultures containing plantain or chicory are likely to convey a dry matter (DM) production advantage over perennial ryegrass (Lolium perenne) at the dairy locations of Terang and Ellinbank in Victoria, and Smithton, Elliott, Cressy and Scottsdale in Tasmania. The growth of monocultures of perennial ryegrass (PRG), plantain (Plantago lanceolata; PLA), and chicory (Cichorium intybus; CHIC), along with mixtures of perennial ryegrass, white clover (Trifolium repens) and plantain (RC-PLA), and mixtures of perennial ryegrass, white clover and chicory (RC-CHIC) were simulated at the six locations for a 40 year period using the biophysical model DairyMod. The average annual yield of PLA ranged between 12.1 and 25.1 tDM/ha and was comparable to or greater than PRG (11.2 to 20.7 tDM/ha) for all locations. For the Victorian locations of Terang and Ellinbank, the average annual yield of CHIC (11.4 and 15.5 tDM/ha respectively) was comparable to PRG (14.5 and 14.4 tDM/ha respectively). At the Tasmanian locations the average annual yield of the CHIC ranged from 5.2 to 16.8 tDM/ha and was lower than PRG (11.2 to 20.7 tDM/ha). The RC-PLA average annual yield ranged from 12.6 to 24.9 tDM/ha and the RC-CHIC average annual yield ranged from 10.1 to 20.4 tDM/ha for all locations. These yields were greater than the average annual yields of PRG. However, for the Tasmanian locations the RC-CHIC had a greater variance in yield (CV's between 8.3 and 27.1%) than the PRG (CV's between 3.1 and 17.2%). The RC-CHIC had greater summer production but lower winter production than the PRG at all locations. At the Tasmanian locations the RC-PLA had greater autumn and winter production than the PRG. It is concluded that the species that best complements the dairy feedbase is chicory or plantain for the Victorian locations and plantain for the Tasmanian locations.

Key words
Alternative forage species, pasture mixtures, biophysical modelling

Introduction

Perennial ryegrass (*Lolium perenne*) pastures form the basis of dairy production in the southern regions of Australia. This species is productive, relatively easy to establish, has well established and understood guidelines for its grazing management, and is relatively responsive to inputs of fertiliser and irrigation water (Rawnsley *et al*. 2014). Perennial ryegrass pastures have a bimodal distribution in growth with maximum growth rates occurring in spring (occurring concurrently with a decline in nutritive value due to reproductive development), followed by a decline in summer production due to temperature and moisture stress. There is a secondary peak in production in autumn followed by a slowing in growth during winter due to low temperatures (Rawnsley *et al*. 2007). This inter-seasonal variation in pasture growth and nutritive value presents a challenge to dairy farmers in terms of managing forage supply and demand within their business.

The perennial forbs plantain (Plantago lanceolata) and chicory (Cichorium intybus) are noted for their superior dry matter (DM) production during summer and autumn, and superior nutritive value compared to perennial grasses. The improvement in DM yield of plantain and chicory is associated with deeper root systems (Neal *et al*. 2009) and tolerance to heat (Stewart 1996) compared to the grasses. The superior nutritive value is associated with lower fibre content (Woodward *et al*. 2008) and a balanced mineral composition (Pirhofer-Walzl *et al*. 2011), and leads to improved animal production (Pembleton *et al*. 2015). It is for these reasons that these species may complement the perennial ryegrass forage base and assist to increase the production and consumption of 'home grown' forage on dairy farms.

While field research in Victoria and Tasmania has identified that both plantain and chicory grown either as monocultures or as components of a mixture can increase forage DM production (Tharmaraj *et al*. 2008, K.G Pembleton unpublished data), there has been contrasting results as to which forb species is the most suitable for a given region. The aim of this study was to identify which regions are most suitable for plantain and

which regions are most suitable for chicory. It achieved this aim by using biophysical modelling to evaluate the production of chicory and plantain as monocultures and in pasture mixtures across six locations that represent major dairy regions in Victoria and Tasmania.

Methods

Model description

The biophysical pasture model DairyMod (version 5.2.15) (Johnson *et al*. 2008) was used for this study. It integrates weather data, soil water dynamics, soil carbon and nitrogen dynamics with plant water uptake and transpiration, canopy photosynthesis, tissue nitrogen dynamics and pasture management (irrigation, fertiliser and grazing management) to simulate plant growth on a daily time step. DairyMod has been used to explore the growth of perennial ryegrass across a range of locations (Chapman *et al*. 2009), the impact of future climates on pasture production (Cullen *et al*. 2009) and the optimising of inputs (Rawnsley *et al*. 2009). Users provide weather data and a description of the soil hydraulic properties, organic carbon and nitrogen pools and inorganic nitrogen pools. Users also define nitrogen fertiliser, irrigation and grazing management rules and select the species that are present in the pasture. The model is released with species specific parameter sets for perennial ryegrass and white clover. Recent research has further defined parameter sets for the forb species plantain and chicory and has confirmed that the model appropriately represents their growth in mixed pastures (Pembleton *et al*. 2015, K.G. Pembleton unpublished data).

Simulations

The growth of monocultures of *perennial ryegrass* (PRG), *plantain* (PLA) and *chicory* (CHIC) along with a mixture of perennial ryegrass, white clover and plantain (RC-PLA), and a mixture of perennial ryegrass, white clover and chicory (RC-CHIC) were simulated over two locations in Victoria (Ellinbank and Terang) and four locations in Tasmania (Smithton, Elliott, Cressy and Scottsdale), using site specific soil and weather data. Details of the soil and climatic conditions at these locations are provided in Table 1.

Each simulation was run using weather data from the years of 1963 to 2013 inclusive. Weather data for each location was accessed from the SILO (Scientific Information for Land Owners) online climate data base (Jeffrey *et al*. 2001). In each simulation the pastures were grazed to a residual height of 1200kgDM/ha on a 6 week rotation with spring calving dairy cows. Nitrogen (N) fertiliser, in the form of urea, was applied after each grazing event between May and January inclusive; 40 kgN/ha was applied in each application. Pasture growth was simulated under dryland conditions at Ellinbank and Terang. At Smithton, Elliott, Cressy and Scottsdale pasture growth was simulated under both dryland and irrigated conditions. In the irrigated simulations 15mm of water was applied on a 20mm rainfall deficit between the months of November and February inclusive. To allow the soil conditions within the model to initialise, the data from the first 10 years of each simulation was discarded from any subsequent analysis.

Table 1. Summary of soil and climate details for each location used in the simulations. Plant available water content (PAWC) is calculated over upper 1m of the soil profile. Climatic information is calculated over the period of the simulations (1963 to 2013 inclusive).

Location	Lat/ Lon	Soil type	PA-WC (mm)	Mean annual rainfall (mm)	Mean monthly maximum/minimum temperature (°C)											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Terang Vic	-38.24/ 142.92	Chromosol	162	774	24.5/ 11.8	25.0/ 12.4	22.8/ 11.2	19.4/ 9.2	15.9 /7.6	13.3 /5.7	12.7 /5.1	13.7/ 5.6	15.4 /6.6	17.6 /7.6	19.9/ 9.0	22.1/ 10.3
Ellinbank Vic	-38.25/ 145.93	Ferrosol	200	1052	24.9/ 12.6	25.4/ 13.1	23.0/ 11.7	19.2/ 9.4	15.7 /7.4	13.2 /5.5	12.5 /4.7	13.7/ 5.4	15.6 /6.6	18.0 /8.0	20.3/ 9.6	22.6/ 11.1
Elliott Tas	-41.08/ 145.77	Ferrosol	200	1184	20.5/ 11.0	20.9/ 11.6	19.2/ 10.3	16.5/ 8.5	13.9 /6.8	11.9 /5.1	11.2 /4.4	11.8/ 4.7	13.1 /5.4	15.1 /6.5	17.1/ 8.2	18.7/ 9.4
Scottsdale Tas	-41.17/ 147.49	Ferrosol	200	987	22.6/ 10.8	22.8/ 11.3	21.1/ 9.9	17.6/ 7.8	14.7 /6.0	12.4 /4.2	11.8 /3.6	12.5/ 4.1	14.1 /5.0	16.3 /6.0	18.6/ 7.8	20.5/ 9.2
Cressy Tas	-41.68/ 147.08	Red tenosol	100	602	29.3/ 10.4	24.1/ 10.4	22.0/ 8.1	18.1/ 6.1	14.7 /3.8	12.0 /1.9	11.6 /1.8	12.6/ 2.3	14.7 /3.9	17.0 /5.4	19.7/ 7.1	22.2/ 8.8
Smithton Tas	-40.83/ 145.11	Hemic Organosols	200	1106	20.5/ 11.3	20.6/ 11/7	19.3/ 10.5	17.0/ 8.7	14.9 /7.1	13.1 /5.5	12.5 /5.0	13.0/ 5.4	14.2 /6.3	15.7 /7.2	17.3/ 8.6	18.9/ 10.0

Results

Annual forage yields of the PRG at the Victorian locations of Terang and Ellinbank were 14.4 and 14.5 tDM/ha respectively (Table 2). The PLA at Terang had a similar average annual forage yield to the PRG, while at Ellinbank the PLA on average outperformed the PRG by 3.9 tDM/ha. There was also considerably less inter-

annual variation in yield (as indicated by the co-efficient of variation) for the PLA compared to the PRG at these two locations. At Terang the CHIC had a lower yield (11.4 tDM/ha) than the PRG, while at Ellinbank the CHIC yield was similar to PRG. At both locations the RC-PLA and RC-CHIC had at least a 2.8 tDM/ha yield advantage over the PRG, along with a reduction in inter-annual variability in yield. For the Tasmanian locations PLA had between a 0.9 to 4.4 tDM/ha yield advantage over the PRG under both dryland and irrigated conditions. The inter-annual variability in yield was similar for the PLA and PRG with coefficients of variation between 2.0 and 19.0%. Growth of the CHIC across the Tasmanian locations was less than the PRG. The RC-PLA had an equivalent or greater average annual yield compared to the PRG across the Tasmanian locations. The RC-CHIC when grown dryland had a lower yield than the PRG at Cressy and Scottsdale and when irrigated at Elliott. In all cases the RC-PLA had a greater yield than the RC-CHIC.

Table 2. Modelled annual forage yields (t/ha) of perennial ryegrass (PRG), plantain (PLA), chicory (CHIC), a mixture of perennial ryegrass, white clover and plantain (RC-PLA) and a mixture of perennial ryegrass white clover and chicory (RC-CHIC) under dryland and irrigated conditions across 6 locations in southern Australia. Values are the mean of the years between 1973 and 2013. The values in parenthesis are the coefficients of variation associated with each mean.

Location	Terang, Vic	Ellinbank, Vic	Smithton, Tas		Elliott, Tas		Cressy, Tas		Scottsdale, Tas	
Irrigation	Dry	Dry	Dry	Irr	Dry	Irr	Dry	Irr	Dry	Irr
PRG	14.5	14.4	16.0	19.7	17.0	20.0	11.2	19.8	17.1	20.7
	(25.7)	(25.4)	(10.5)	(3.1)	(9.2)	(4.1)	(17.2)	(8.9)	(9.6)	(5.7)
PLA	14.4	18.3	18.0	23.5	17.1	20.9	12.1	23.4	18.7	25.1
	(18.8)	(13.4)	(11.8)	(2.8)	(10.7)	(3.0)	(19.0)	(6.4)	(11.5)	(2.0)
CHIC	11.4	15.5	12.2	11.4	8.6	16.8	5.2	10.0	10.0	11.3
	(30.6)	(27.4)	(37.1)	(58.6)	(35.3)	(24.9)	(36.6)	(47.7)	(36.6)	(52.2)
RC-PLA	17.9	19.0	18.9	24.0	17.5	19.9	12.6	23.9	19.3	24.9
	(10.3)	(15.7)	(12.7)	(3.0)	(9.9)	(10.9)	(17.9)	(8.9)	(13.0)	(5.7)
RC-CHIC	17.2	18.4	16.8	20.4	17.3	19.6	10.1	18.5	16.4	20.4
	(12.1)	(11.3)	(15.5)	(11.3)	(14.7)	(8.3)	(27.1)	(14.1)	(15.3)	(9.9)

Table 3. Modelled monthly growth rates (kgDM/ha) of perennial ryegrass (PRG), plantain (PLA), chicory (CHIC) and a mixture of perennial ryegrass, white clover and plantain (RC-PLA) and perennial ryegrass white clover and chicory (RC-CHIC) under dryland conditions across 6 locations in southern Australia. Values are the mean of the years between 1973 to 2013. The values in parenthesis are the coefficients of variation associated with each mean.

Location	Species/ mixture	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Terang	PRG	39 (101)	28 (139)	26 (112)	35 (97)	33 (80)	31 (86)	33 (74)	50 (69)	60 (71)	52 (99)	42 (115)	47 (111)
Vic	PLA	34 (96)	29 (115)	18 (115)	23 (100)	25 (74)	28 (58)	34 (46)	50 (44)	59 (50)	65 (56)	63 (73)	43 (90)
	CHIC	44 (81)	33 (87)	29 (92)	37 (77)	23 (65)	6 (100)	2 (175)	4 (104)	16 (89)	42 (50)	69 (52)	69 (65)
	RC-PLA	35 (81)	20 (93)	20 (105)	28 (91)	36 (63)	38 (53)	48 (47)	57 (50)	72 (44)	85 (43)	88 (38)	61 (60)
	RC-CHIC	46 (63)	43 (60)	34 (51)	36 (57)	27 (54)	13 (104)	10 (118)	31 (75)	76 (38)	96 (43)	93 (35)	61 (57)
Ellinbank	PRG	37 (113)	20 (135)	24 (114)	35 (98)	38 (73)	32 (70)	32 (76)	49 (69)	56 (75)	54 (94)	46 (100)	52 (93)
Vic	PLA	25 (96)	15 (129)	15 (132)	26 (88)	37 (46)	45 (25)	56 (16)	76 (16)	88 (18)	93 (20)	71 (39)	51 (64)
	CHIC	72 (50)	62 (68)	46 (90)	43 (80)	25 (71)	6 (96)	2 (207)	3 (132)	12 (113)	46 (64)	90 (46)	103 (46)
	RC-PLA	29 (86)	20 (104)	21 (95)	41 (63)	52 (42)	50 (40)	46 (47)	57 (52)	82 (36)	94 (30)	78 (37)	57 (62)
	RC-CHIC	61 (46)	53 (55)	47 (63)	43 (54)	27 (54)	15 (96)	19 (110)	39 (74)	67 (42)	91 (42)	81 (44)	63 (50)
Elliott	PRG	55 (44)	40 (62)	32 (67)	28 (69)	29 (53)	24 (64)	26 (54)	42 (29)	56 (15)	72 (8)	79 (14)	75 (33)
Tas	PLA	49 (51)	35 (60)	28 (67)	33 (42)	32 (28)	32 (20)	35 (17)	46 (9)	60 (6)	75 (7)	72 (15)	64 (34)
	CHIC	46 (77)	43 (80)	38 (83)	30 (90)	12 (103)	2 (102)	1 (131)	1 (127)	4 (116)	14 (99)	38 (70)	56 (78)
	RC-PLA	53 (43)	44 (49)	36 (44)	35 (49)	34 (30)	26 (45)	32 (33)	40 (27)	59 (12)	74 (13)	74 (26)	68 (31)
	RC-CHIC	67 (40)	69 (45)	53 (50)	37 (58)	25 (49)	15 (73)	18 (78)	29 (49)	47 (43)	69 (69)	73 (30)	68 (31)
Scottsdale	PRG	46 (59)	36 (65)	26 (80)	32 (57)	32 (44)	28 (50)	30 (43)	44 (25)	60 (11)	78 (10)	80 (16)	68 (41)
Tas	PLA	42 (62)	32 (62)	28 (70)	35 (48)	37 (28)	39 (21)	42 (17)	57 (8)	72 (4)	88 (9)	78 (21)	64 (45)
	CHIC	56 (56)	50 (65)	34 (87)	30 (65)	14 (88)	4 (118)	2 (150)	4 (157)	11 (114)	21 (88)	47 (60)	56 (52)
	RC-PLA	45 (59)	32 (63)	31 (64)	36 (51)	41 (21)	37 (28)	42 (21)	59 (10)	77 (8)	89 (12)	81 (23)	63 (45)
	RC-CHIC	51 (43)	57 (46)	45 (54)	36 (36)	21 (59)	13 (79)	21 (75)	38 (48)	55 (41)	71 (25)	72 (30)	61 (39)
Cressy	PRG	19 (116)	11 (127)	11 (142)	21 (76)	21 (66)	26 (59)	31 (47)	45 (25)	59 (16)	59 (35)	36 (665)	29 (85)
Tas	PLA	16 (117)	8 (139)	9 (159)	17 (83)	26 (47)	28 (36)	40 (18)	57 (8)	66 (20)	61 (39)	37 (58)	30 (75)
	CHIC	29 (82)	19 (105)	15 (101)	12 (93)	7 (121)	2 (109)	1 (220)	1 (166)	6 (103)	15 (105)	26 (79)	38 (63)
	RC-PLA	20 (96)	12 (113)	14 (97)	20 (80)	26 (53)	30 (42)	36 (33)	55 (11)	69 (19)	63 (41)	39 (60)	31 (75)
	RC-CHIC	28 (73)	23 (99)	20 (79)	18 (59)	11 (83)	7 (72)	18 (86)	33 (59)	51 (45)	52 (47)	38 (60)	31 (74)
Smithton	PRG	51 (48)	28 (81)	24 (76)	32 (60)	27 (56)	26 (51)	26 (49)	44 (24)	56 (12)	73 (9)	75 (14)	64 (37)
Tas	PLA	46 (53)	28 (70)	28 (64)	35 (41)	35 (23)	33 (26)	38 (20)	53 (12)	67 (5)	81 (8)	80 (17)	65 (37)
	CHIC	51 (65)	45 (75)	35 (82)	34 (72)	22 (71)	9 (83)	7 (102)	11 (95)	25 (78)	36 (64)	63 (41)	63 (55)
	RC-PLA	48 (54)	31 (64)	28 (57)	39 (41)	36 (30)	34 (25)	40 (26)	56 (11)	69 (11)	86 (7)	84 (18)	68 (35)
	RC-CHIC	61 (39)	55 (52)	45 (41)	41 (48)	24 (53)	18 (53)	22 (65)	31 (58)	52 (30)	66 (30)	70 (29)	70 (36)

Under dryland conditions the CHIC was able to maintain greater growth rates into the summer months compared to the PRG (Table 2). However, the CHIC also had lower growth rates in winter and spring due

to the expression of winter dormancy. This response also carried through into the RCCM. Compared to the PRG, the PLA and RCPM had greater late spring growth at the Victorian locations and greater autumn growth at the Tasmanian locations.

Discussion

This study suggests that using a RCPM in Tasmania and a RCPM or RCCM in Victoria can increase forage yields. For locations in Victoria these mixtures also reduce the inter-annual variability in yield. This modeling is confirmed by field observations of pasture mixtures that contain plantain and/or chicory exploiting temporal niches that develop within dairy pastures (Pembleton *et al*. 2015). While the PLA and CHIC were able to change the distribution of forage yield to produce forage when the PRG growth was low due to high temperatures and soil moisture deficits, they still had considerable variability in yield. This variability, coupled with the challenges that the PLA and CHIC present in terms of management and plant persistence (Pembleton et al. 2015), will limit their use on dairy farms. Furthermore, the growth of the CHIC during the winter months was constrained by the winter dormancy displayed by this species and hence they are unsuitable for regions with cold winters (i.e. Tasmania).

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An investigation of the social sustainability of genetically modified rye grass forage in New Zealand

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Abstract
Social sustainability is a component of the sustainability construct. We discuss the nature of social sustainability of new technologies considering what this might mean for emerging, controversial technologies. Next, to consider the social sustainability of a new GM rye grass, we compare the results of a series of surveys, conducted in each of the following years, 2001, 2003, 2005, 2009 and 2013. These surveys examined public moral values towards, the use of GM technology for food and medicine, GM rye grass, feeding GM forage to food animals, and the consumption of milk and meat products derived from animals fed on GM rye grass (with and without consumer health benefits). Although demonstrating slight volatility, NZ public moral values have not changed substantively over the period of the surveys. While the public's general moral values towards GM medicines are quite accepting (moral support is greater than opposition), their general moral values regarding GM food are wariness and slight repugnance (moral opposition is greater than support). Nonetheless, the majority are prepared to accept GM food under some circumstances (e.g., GMOs with specific useful attributes). They are less apprehensive about GM forage, but moral opposition is still greater than support, and moral concern about environmental impacts is evident. The public are more accepting of GM forage if human health benefits occur from consuming products derived from animals fed on GM forage or if there are environmental benefits from the cultivation of GM forages. Perceived positive consequences of the technology help mitigate general moral concerns.

Key words
GM food, moral values, empirical ethics, public perceptions, attitudes

Introduction

The New Zealand pastoral sector relies primarily on pasture based feed. AgResearch has develop a genetically modified (GM) rye grass with the potential to "transform New Zealand's pasture based feed supply, increasing productivity while minimising environmental impacts" (Bryan, 2015, p.3). Specifically, the modified rye grass has increased growth rates of 25-50% with a 10% increase in metabolisable energy (ME). Modelling indicates that animals fed the increased ME GM rye grass may have increased productivity (estimated at 6-12% for dairy milk solids) and reduced greenhouse gas emissions (estimated at 10% for methane emissions and 17% for N_2O emissions). Currently, the GM rye grass is at the trait fixing stage and contained in PC2 glasshouses. It is envisaged that field trials will be possible in 2017 and animal feeding trials possible in 2020 (Bryan, 2015).

In the past, the New Zealand public displayed reservations about GM technology, consuming genetically modified organisms (GMOs) and about the release of GMOs into the New Zealand environment. In this paper we briefly consider the construct of social sustainability in relationship to new and emerging technologies and then report on longitudinal empirical ethics research conducted with the New Zealand public regarding their moral values and attitudes to the use of GM technology for food and medicine, the production and release of GM rye grass, feeding GM forages to animals, and consuming products (i.e., meat and milk) from animals fed on GM forages (with and without human health benefits).

Sustainable development, as defined by the Brundtland Report (The World Commission on Environment and Development, 1987), is "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition is a moral imperative about intra and intergenerational equity. Euston and Gibson (1995) assert sustainability is a moral goal defined as "a condition in which natural systems and social systems survive and thrive together indefinitely". Social sustainability, along with environmental sustainability, economic sustainability and institutional sustainability, is a component of the sustainability construct. Social sustainability is still under definition in

the academic literature (Dempsey et al., 2011). Littig and Griessler (2005) identified three dimensions of social sustainability 1) satisfaction of basic needs and quality of life, 2) social justice (regarding distribution of economic goods, equal opportunities, participation in society), and 3) social coherence. Euston and Gibson (1995) also include 'respect for community' and 're-dedication to civic democracy and civic dialogue'.

Applying the concept of social sustainability to new and emerging technologies suggests the public have a right to participate in civic dialogue about the technology and its deontological moral value (intrinsic value –irrespective of consequences), and its potential applications and moral consequences (teleological ethics). Furthermore, their moral views and attitudes should be respected in relevant policy, technological development and release. Social sustainability is dependent upon the social context (e.g., community, region, and nation) under analysis and may vary across time, place, and culture, along with the system conditions and normative values. Public participation in the development of sustainability policies and moral assessment of emerging technologies may help enable appropriate social contextualisation (Small, 2007). A new ethical development, empirical ethics, uses social science methodologies to combine descriptive ethics (i.e., people's actual moral beliefs and behaviour) with normative ethical analysis (i.e., deontological and teleological ethical reasoning). Social science methodologies, such as randomised surveys can provide quantitative information about the prevalence and strength of specific moral beliefs in a society regarding a technology, while qualitative techniques such as interviews and focus groups can help explain why they hold those beliefs. Empirical ethics is a useful tool for dealing with new problems for which rules, principles and values, have not yet been developed by society (Borry et al., (2004). For a more a more in-depth analysis of social sustainability of emerging technologies and empirical ethics see Small (2007).This paper reports quantitative data from survey research.

Method

This paper summarises five randomly distributed quantitative surveys of the New Zealand public, conducted between 2001 and 2013, that examine the New Zealand public's moral values and attitudes regarding genetic modification. All five surveys have similar demographic profiles which are roughly representative of the 15+ years New Zealand population, making them broadly comparable. Four of the surveys were conducted by Small, one each in 2001 (n =1672), 2003 (n = 964), 2005 (n = 863) and 2009 (n = 1008). A fifth survey was conducted in 2013 (n = 353) by Chikazhe (2015) as part of a Master thesis. All five surveys contained approximately 100 questions, the large majority of which were replicated in each survey, allowing a comparison of data over time. Results have been published in reports, conference papers, journal articles, a Master Thesis, and a book chapter. Spatial limitations on this paper only allows presentation of selected data and results, from the above surveys, relevant to the question of public moral values regarding support for GM food and medicine, the production and release of GM forage crops, feeding GM crops to food animals, the human food produced from these animals, and purchase and consumption of these products. Note that the focus of the paper is on respondents' beliefs (as opposed to the veracity of the belief) and values, because these are the drivers of their assessment of the technology and their behaviour regarding it.

Results and discussion

Support for GM food and GM medicines

Over the five surveys, total support for GM food ranged from 3% to 9%, conditional support ('I would support GM food under some circumstances') ranged from 47% to 61%, and total opposition to GM food ranged from 21% to 36%. 'Don't know' responses ranged from 4% to 20%. Opposition to GM food was greater than support at all time points. Despite some temporal volatility, there was little overall change between the 2001 and 2013 surveys in general attitudes to GM. Support for GM food showed no clear trend for change over time with support being lowest in 2001 followed by 2013 then 2009, and highest in 2003 and 2005 (approximately equal). However, over the time period there was a trend of increasing uncertainty regarding GM food, with a gradual increase in 'don't know' responses.

Total support for GM medicine, over the five surveys, ranged from16% to 33%, conditional support ranged from 45% to 62% and total opposition to GM medicine ranged from 7% to 16%. 'Don't know' responses ranged from 3% to18%. Support for GM medicines was greater than opposition at all time points. Similar to the GM food case, no clear change trends emerged overtime, however, the pattern of high and low years was the same for both GM food and GM medicine and overall change between 2001 and 2013 was relatively small. 'Don't know' responses also tended to increase over time. The public were considerably more accepting of GM medicine than they were of GM food.

The need for case-by-case evaluation of GM products

Despite general moral opposition to GM food, at all time points, more than 50% of the public were prepared to support it under some circumstances. A similar percentage was also prepared to support GM medicines under some circumstances. With the majority of respondents giving at least conditional support (i.e., 'total support' or 'conditional support') to both GM food and GM medicines, this suggested the need for a case-by-case evaluation of GM products rather than totally accepting or totally opposing all applications of GM. Small asked about the need for case-by-case evaluation in his 2009 survey and 59.3% of respondents either agreed or strongly agreed. A further14.2% disagreed or strongly disagreed with the remainder either neutral (16.7%) or unsure (9.8%). These results (and further survey data not reported in this paper) suggest that circumstances and purposes surrounding development of the technology, attributes of the GM products, their use and consequences could be important factors influencing public acceptance to specific products.

Attitudes and values towards GM forage crops

Due to space limitations, rather than presenting data across all time periods, the tables below present data from Small's 2009 survey. This is the year in which support for GM food and medicine reached its median value and as such it is approximately representative across the 12 year period of the five studies. Table 1 presents the sample respondents' level of agreement (in percentages and means) with statements regarding general attitudes and values towards GM forage crops and towards some specific proposed engineered attributes.

Table 1. Attitudes and values towards GM forage plants: response frequency (%) and means (2009, n = 1008)

Statement	Strongly agree		Neutral		Strongly Disagree	Don't Know	Mean	SD
	1(%)	2(%)	3(%)	4(%)	5(%)	(%)	M[1]	SD
Modifying plants using GM technology fits with my basic moral principles.	5.46	13.69	26.79	15.58	23.21	15.28	**3.44****	1.23
GM forage crops are environmentally friendly.	3.17	9.33	23.21	11.90	16.47	35.91	**3.46****	1.16
It is acceptable to feed animals that people eat (e.g., cows, sheep) forage crops developed using GM	7.54	15.87	25.00	15.18	21.92	14.48	**3.33****	1.28
Feeding animals GM forage crops with high levels of available energy is an acceptable way to increase animal production.	6.75	18.65	23.02	13.10	20.34	18.15	**3.26****	1.28
Feeding animals GM forage crops is acceptable if it results in human health benefits.	11.11	21.43	22.92	14.68	16.17	13.69	**3.04ns**	1.30
Feeding animals GM forage crops is acceptable if it reduces the production of greenhouse gases (methane) responsible for climate change.	9.42	21.33	24.40	11.90	16.37	16.57	**3.05ns**	1.28

[1] mean was calculated after the removal of 'Don't know' responses,

**p<0.001 – significantly different from neutral midpoint of scale (2-tailed ZTEST)

As can be observed from Table 1, respondents quite strongly disagreed that GM plants fit with their basic moral principles, that GM crops are environmentally friendly, and that it is acceptable to feed food animals GM crops. Note that there was considerable uncertainty regarding these issues with more than a third of respondents being unsure as to whether GM forage crops are environmentally friendly. Feeding high ME GM crops to increase production was also relatively unacceptable. However, if feeding animals GM crops resulted in human health benefits or reduction of greenhouse gases, respondents were almost neutral with approximately as many agreeing as disagreeing that it is acceptable. For these two items the mean was not significantly different from the neutral point of the scale. Positive consequences for the environment or consumer health appear to mitigate moral reservations about GM.

Attitudes and values towards food derived from animals fed on GM forage crops

Table 2 presents the sample responses level of agreement (in percentages responses and means) with statements regarding attitudes and values towards food products derived from GM forage crops.

Table 2. Attitudes and values towards food derived from animals fed on GM forage crops: response frequency (%) and means (2009, n=1008)

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know	Mean	SD
	1(%)	2(%)	3(%)	4(%)	5(%)	(%)	M[1]	SD
Milk and meat products derived from animals fed on GM forage will be safe products to develop.	3.67	11.31	22.72	13.29	16.77	32.24	**3.42****	1.18
If these milk and meat products were available in the shops, I would definitely buy them for myself.	5.65	12.80	22.02	17.46	25.60	16.47	**3.53****	1.26
Consuming products from animals fed on GM forage crops is acceptable to me if predicted to result in a 10% reduction in heart disease.	9.03	21.83	22.42	15.08	15.28	16.37	**3.07ns**	1.27
These milk and meat products will be useful products to develop.	7.74	21.53	23.12	13.69	15.48	18.45	**3.09***	1.25

[1] mean was calculated after the removal of 'Don't know' responses,
* $p<0.05$ – significantly different from neutral midpoint of scale (2-tailed ZTEST)
**$p<0.001$ – significantly different from neutral midpoint of scale (2-tailed ZTEST)

Respondents expressed a high level of disagreement that they would buy food products from animals fed on GM forage or that the products would be safe (however, almost one third of respondents answered 'Don't know' to this latter question, indicating a considerable degree of uncertainty). Despite the concern about safety, if using these products resulted in a 10% reduction in heart disease then consuming them is acceptable to approximately 30% of respondents and unacceptable to an equal number (however, nearly 40% were either neutral or uncertain). The mean score for this item is not significantly different from the neutral midpoint of the response scale. There was significant ($p<.05$) disagreement that the products would be useful. Positive consumer health consequences mitigated concerns about eating these food products.

Conclusion

Over the 12 year period that these five studies encompassed New Zealand public values regarding GM have remained relatively stable with no real discernible trends apart from a steady increase in public uncertainty. The general moral unease towards GM food and GM forage, and moral concern about negative environmental consequences and human and animal safety, suggest potential social sustainability issues for these emerging technologies. However, it is also apparent that these concerns can be mitigated by positive attributes or consequences of the GMO in question. Data presented here indicate that having environmental and/or human health benefits can increase public acceptance of GMOs and products from animals fed on GMOs. Despite moral reservations, the majority of the public are prepared to support GM food under some circumstances and support case-by-case evaluation of GM products. The five surveys are a valuable source of ethical data that may help to determine the moral attributes of GM technologies acceptable to the public.

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Sirolan phalaris and Kasbah cocksfoot prove more persistent than lucerne under drought in a medium rainfall cropping environment

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Abstract
Cultivars of phalaris (*Phalaris aquatica* L.) and cocksfoot (*Dactylis glomerata* L.) suited to lower rainfall cropping environments have existed in Australia for over 40 years, but remain rarely used in commercial crop rotations. A field experiment was established in 2010 at Ariah Park, NSW, to test the persistence of phalaris cv. Sirolan and cocksfoot cv. Kasbah compared to winter active and semi-winter dormant lucerne (*Medicago sativa* L.) cultivars on a red soil where the average annual rainfall is 460 mm. All treatments established successfully in 2010 and persisted well through the summers of 2010/11 and 2011/12 which were both substantially wetter than average. A rapid reduction in perennial plant density was observed in all treatments following the dry spring/summer period of 2012/13. However, the basal frequency of Sirolan phalaris (19%) and Kasbah cocksfoot (25%) was greater than either winter active or semi-winter dormant lucerne genotypes (4-5%). Sirolan was the most productive of all perennial treatments, producing significantly more dry matter than lucerne in years 1, 4 and 5. Kasbah cocksfoot was more productive than lucerne in year 5 only, but was significantly less productive in year 2. This study showed that the perennial grasses were productive and persistent in this environment and their greater use could benefit modern crop rotations.

Key words
Pasture mixture; production; winter activity

Introduction
Lucerne (*Medicago sativa* L.) is the most widely used perennial pasture species in winter-cropping systems of south-eastern Australia. It is broadly adapted and is highly valued in mixed farming systems for its ability to produce high quality forage for livestock and fix nitrogen (N) for subsequent crops. However, there is a need for viable alternatives to lucerne in these farming systems to improve the balance of seasonal pasture production and to mitigate the low levels of groundcover in lucerne swards. Cool-season perennial grasses are arguably one of the few viable options that exist in these environments (Hayes *et al*. 2012). They have been shown to be able to survive in phased rotations in lower-rainfall mixed farming environments (Dear *et al*. 2004), although adoption remains relatively low, due in part to perceived lower production and poor persistence of these species relative to lucerne (Hayes *et al*. 2010). The current study tested the production, persistence and relative ground cover of two cool-season grasses, Sirolan phalaris (*Phalaris aquatica* L.) and Kasbah cocksfoot (*Dactylis glomerata* L.), compared to winter active and semi-winter dormant lucerne types over 5 years at a site in the medium rainfall cropping zone of southern NSW.

Method
A field experiment was sown near Ariah Park, NSW (34.35S, 147.22E), on 7 May 2010 using a cone seeder. Treatments reported here include Kasbah cocksfoot (sown at 3 kg/ha of germinable seed), Sirolan phalaris (2.5 kg/ha), winter active lucerne (dormancy rating 9-10, where 1 is most dormant and 10 is most active) comprising an equal mixture of cultivars Cropper 9.5, Sardi 10 and Silverado sown at a total of 2.5 kg/ha and an equal parts mixture of semi-winter dormant lucerne (dormancy rating 4-5) cultivars (Venus, Stamina 5 and 54Q53) sown at 2.5 kg/ha. All treatments were mixed with 4 kg/ha subterranean clover (*Trifolium subterraneum* L.) cv. Urana. All legume seed was inoculated with appropriate rhizobia groups and lime pelleted prior to sowing. The results of the annual legume component of the sward will be reported elsewhere. Plot size was 6 × 4 m. Starter fertiliser (6.7% N, 13.9% P, 8.6% S) was applied at 120 kg/ha at sowing and single superphosphate (8.8% P, 11% S) was top-dressed annually at approximately 100 kg/ha. In the year of establishment annual grass weeds were removed by hand.

Persistence of sown species was assessed as basal frequency by counting the presence of a perennial base (crown) in two fixed 1 × 1 m quadrats containing 100 squares, expressed as a percentage of the total number

of squares. Basal frequency was measured 12 weeks after sowing in year 1, and shortly after the first rains in autumn in years 2-5. Above ground biomass was assessed at the end of spring in the establishment year and at the end of every season thereafter using a calibrated visual assessment. The botanical composition of each sward was assessed at the same time as available biomass by using the dry-weight rank method (t' Mannetje and Haydock 1963) on 10 quadrats across a transect of each plot. Following each assessment of biomass the site was grazed with a high stocking rate of sheep leaving a residual biomass of approximately 1 t/ha across the site. Exposed bare ground was assessed in November 2011 and subsequently in early autumn in each year thereafter by counting the number of squares containing no plant material, including litter, in the above-mentioned fixed quadrats. Data is expressed as a percentage of quadrat squares containing no plant material. All data were analysed using an analysis of variance at the 95% confidence level.

Results

The site experienced wetter than average conditions in the first 3 years of experimentation, with years 4 and 5 being drier than average (Table 1). The period from September 2012 to February 2013 was extremely dry with very few substantial rainfall events, and proved to be a significant turning point for the persistence of perennial pasture species in this experiment.

Table 1. Monthly rainfall (mm) recorded near the experimental site 2010-14 compared to the long term (120 year) median and average for that location (Source: Bureau of meteorology; station 73000).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2010	10.2	67.8	73.6	34.2	74.4	19.6	65.8	53.2*	64.4	114.3	66.0	84.6	728.1
2011	49.6	203.8	72.8	21.2	23.8	20.0	18.0	49.4	28.4	29.0	92.0	82.0	690.0
2012	81.0	111.4	125.2	7.4	43.6	30.8	42.2	41.2	9.0	12.8	34.0*	13.2	551.8
2013	1.0	42.0	23.4	2.8	53.8	87.2	39.4	26.8	40.4	15.8	14.8	12.8	360.2
2014	20.0	25.6	40.0	53.0	32.2	69.4	27.4	16.0	34.8	16.4	31.8	16.6	383.2
Mean	28.0	22.0	24.0	23.1	30.9	36.2	38.9	36.7	30.9	36.3	34.2	31.0	463.9
Median	42.5	38.1	38.8	35.9	37.8	42.3	41.8	37.5	37.4	44.3	39.6	40.6	481.5

* Values unavailable from Ariah Park recording station so taken instead from Barmedman

All treatments established successfully with higher initial seedling density for cocksfoot and phalaris and lower seedling density for both winter active and semi-winter dormant lucerne (data not shown). Establishment differences were reflected in the initial measurement of basal frequency in July 2010 (Fig.1A). Following the first summer differences in basal frequency between treatments were not significant at P=0.05, until the final sampling in 2014 where the basal frequency of the two grasses was significantly greater than both lucerne types (Fig. 1A). Differences in levels of groundcover between treatments were only significant at P=0.05 in 2013 where the level of exposed bare ground was higher in the semi-winter dormant lucerne than either grass treatment (Fig 1B).

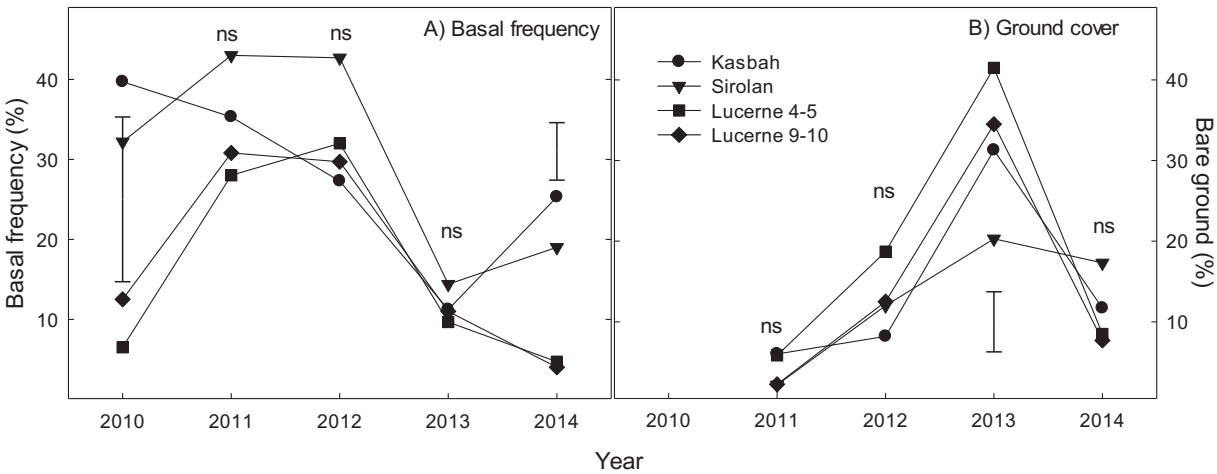

Fig. 1. A) Basal frequency (%) of sown perennial species and B) area of each sward where the soil surface was exposed, at one sampling time in each year for swards sown to Kasbah cocksfoot, Sirolan phalaris, semi-winter dormant (4-5) or winter active (9-10) lucerne. Error bars show differences between treatments at P=0.05, otherwise marked 'ns'.

Sirolan phalaris was the most productive sown species in this experiment with significantly more biomass compared to cocksfoot or either of the lucerne treatments, especially in years 1 and 4 (Figure 2). In both of those years the level of available Sirolan phalaris biomass was more than double that of any other treatment. By contrast, Kasbah cocksfoot was the most productive sown perennial species in year 5 although this was the only occasion where there was significantly (P=0.05) greater cocksfoot biomass than phalaris.

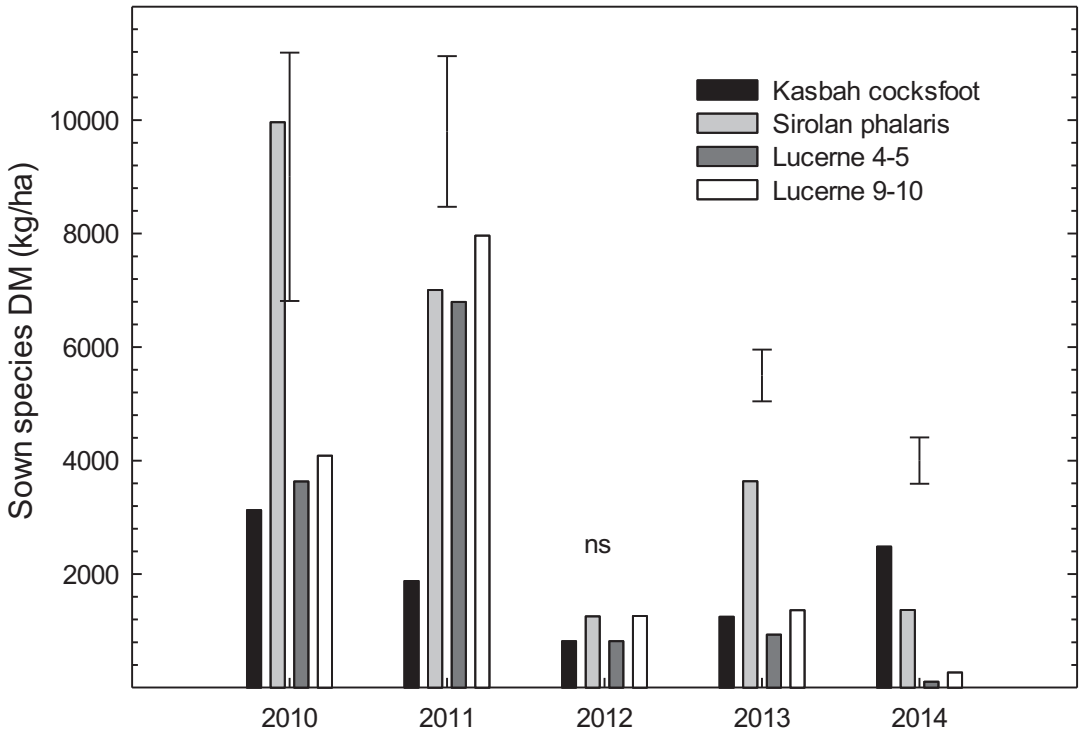

Fig. 2. Sown species available biomass (kg/ha) across 5 years. Vertical bars represent LSD at $P < 0.05$. ns; not significant.

Discussion

The experiment demonstrated that Sirolan phalaris and Kasbah cocksfoot can be more productive and persistent than lucerne over a 5-year pasture phase in the medium rainfall environment of southwest NSW. Sirolan phalaris in particular was able to take advantage of favourable seasonal conditions during the establishment year to produce almost 10 t/ha of aboveground biomass, more than double that of either lucerne or Kasbah cocksfoot. It was the most productive perennial species in year 4 which also happened to be the driest year of experimentation (Table 1), made possible by its high winter activity. The performance of Sirolan over a range of seasonal conditions highlights its broad adaptation to this environment. Sirolan phalaris was bred for lower rainfall cropping environments in south-eastern Australia and was released in 1978 (Oram 1990). There remain few phalaris genotypes which can out-yield Sirolan in medium-low rainfall cropping environments (Culvenor et al. 2012).

Kasbah cocksfoot is a highly summer-dormant public cultivar collected from a semi-arid environment in southern Morrocco receiving approximately 270 mm rainfall a year, and was released commercially in Australia in 1970 (Oram 1990). It is perhaps not surprising that it persisted through the drought period in years 3 and 4 and recovered to be the most productive perennial species in year 5 of this experiment. The significantly lower levels of production of Kasbah cocksfoot in year 2 was of particular interest given that this was generally a favourable year for pasture production, with November, December, February and March, being substantially wetter than normal (Table 1). A substantial amount of rainfall in this year fell during the summer period when Kasbah cocksfoot would normally be dormant. The authors noted that Kasbah was less summer dormant than expected in the summer of 2010/11 and less productive than expected during the following cooler months of 2011. The reason for this is not clear as previous studies have shown this cultivar to have a very strong summer dormancy mechanism (Norton et al. 2006). We postulate that abnormally low summer temperatures in addition to higher summer rainfall reduced the ability of Kasbah cocksfoot to enter summer dormancy which had a negative impact on the overall performance of this cultivar during the earlier

years of experimentation. Nevertheless, Kasbah recovered during the drier years to produce the highest dry matter in year 5.

We found very little difference in the overall performance of lucerne regardless of whether it was winter active or semi-winter dormant. In no year did either group produce more total biomass than the other, nor did one persist better than the other. Levels of groundcover in the year following the period of drought did not differ between lucerne genotypes, however, differences in levels of bare ground between the summer active lucerne compared with Sirolan phalaris were significant at P=0.05. The superior persistence of both Kasbah cocksfoot and Sirolan phalaris compared to both lucerne treatments after the extended dry period is another important result and provides field validation to earlier glasshouse studies showing that Kasbah has better dehydration tolerance than lucerne (Volaire 2008). These results suggest that in such drought prone environments these perennial grasses could add value to mixed farming enterprises. More thorough analysis of the data is necessary to evaluate aspects such as seasonal production, but this initial data set provides little evidence that winter activity group affects lucerne persistence in this environment. This is contrary to a previous study which showed highly winter active varieties to be less persistent under a more continuous grazing regime (Humphries et al. 2006). However, given the high stocking rates (12-80 dry sheep equivalent/ha) used to realise these differences, it remains questionable whether differences in persistence between winter activity groups would be significant in a paddock situation under the extensive grazing regime commonly imposed on lucerne pastures in the medium-rainfall cropping zone of NSW.

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The development of a mid-season barrel medic (*Medicago truncatula* Gaertn.) cultivar with tolerance to sulfonylurea herbicide residues

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Abstract
Sulfonylurea (SU) herbicides are extensively applied to crops in the cereal-livestock zones of southern Australia. In neutral-to-alkaline soils SU residues persist at levels which are potentially harmful to sensitive crops for 1-5 years. The early season strand medic cultivar Angel and the early season barrel medic cultivar Sultan-SU are tolerant of SU residues. However no mid-season barrel medic cultivars with SU tolerance have been released. A cohort of mid-season barrel medics with tolerance to SU residues and aphid resistance were developed and then field evaluated at two sites in the absence of SU residues. All breeders' lines performed well at both the alkaline site and the mildly acidic site. The line Z2504 was chosen for release as a cultivar. Z2504 is segregating for SU tolerance and in 2015 we will use a diagnostic molecular to find plants which are homozygous for SU tolerance and start the seed increase of the new cultivar. The new cultivar is likely to be amongst the first pasture legume cultivars released that have used marker assisted selection in their development. The new cultivar will enable farmers in medium rainfall areas to successfully grow barrel medic pastures in the presence of SU herbicide soil residues resulting from applications to prior crops.

Keywords
Trifolium subterraneum, *Medicago polymorpha*, acidic soils.

Introduction
Barrel medics (*Medicago truncatula*) are widely utilised in ley farming systems in Australia (Nichols *et al*. 2012). They provide high quality feed to livestock and benefit subsequent cereal crops by fixing nitrogen and reducing levels of cereal diseases. High levels of hardseed allow barrel medics to survive 2-3 years of cereal crops and to then self regenerate in the autumn following the last cereal crop. However SU herbicides are widely applied to cereal crops and their residues can adversely affect the performance of following crops and pastures in neutral to alkaline soils where they can persist at potentially damaging levels for 1-5 years (Hollaway *et al*. 2006). Two years after an SU application, reductions in barrel medic drymatter of up to 75% have been reported (Black *et al*. 1999).

The strand medic (*M. littoralis*) cultivar Angel has good tolerance of SU herbicide residues (Peck and Howie 2012). The SU tolerance gene has been transferred from Angel into the more widely grown barrel medic by way of an inter-specific cross followed by backcrossing into barrel medic (Oldach *et al*. 2008, Peck and Howie 2012). An early season cultivar (Sultan-SU, Howie 2015) was released in 2014 but up until now no mid-season barrel medic cultivar has been developed. This paper reports on the development of a mid-season barrel medic cultivar that is tolerant of SU herbicide residues.

Materials and Methods
Breeding
SU tolerance from the strand medic cultivar Angel was transferred to the male sterile mutant barrel medic line "tap" by way of an inter-specific cross followed by five backcrosses (Oldach *et al*. 2008). Pollen from F_1 BC_5 was used to fertilise an emasculated flower of the aphid resistant (bluegreen, BGA, *Acyrthosiphon kondoi*; and spotted alfalfa aphid, SAA, *Therioaphis trifolii*) mid-season cultivar Jester. Jester and "tap" are closely related (Jester is an aphid resistant line backcrossed into Jemalong three times and "*tap*" is a male sterile mutant of Jemalong). F_2 plants were selected for SU herbicide tolerance and dry matter production and progeny tested to identify plants homozygous for BGA and SAA resistance (validated in later generations). These were allowed to self pollinate. For the lines with the best field performance we grew F_6 plants as spaced plants and selected the best plants on drymatter production and pooled these.

We reviewed the field performance and SU tolerance of lines and identified the preferred line (Z2504) for release as a cultivar. In 2015 we will grow spaced plants of Z2504 and use a diagnostic marker for SU tolerance (Oldach *et al*. 2008) to identify homozygous SU tolerant plants. Seeds will be collected from these plants and then further increased in 2016 and 2017 to the levels required for commercial release.

Field evaluation

Breeding lines were field evaluated at Mallala (SA, pH 7.7_w, sown 6/7/2012) and Temora (NSW, pH 4.8_{CaCl2}, sown dry 16/5/2012) in the absence of SU herbicide residues, to determine their agronomic performance relative to cultivars of barrel medic and burr medic (*M. polymorpha*) (table 1). At Temora we also included cultivars of subclover (*Trifolium subterraneum* ssp. subterraneum and ssp. brachycalycinum). Seeds were sown at a rate of 10 kg/ha into a spatially designed, randomised block with three replicates and individual plot size of 4 x 1.2 m. Trials were measured (drymatter and seed yields) and managed as described in Peck and Howie (2012).

Symbiotic Performance

The symbiotic compatibility of breeders lines Z2481, Z2487, Z2504 with the commercial rhizobia inoculant strain (Group AM; *Sinorhizobium medicae* strain WSM 1115) and a new strain (*S. medicae* strain SRDI 554, Bonython et al. 2011) proposed for use on messina (*Melilotus siculus*) was determined and compared with the symbiotic compatibility of cultivars Jester, Caliph and Sultan-SU. Four treatments were applied to seedlings established in N deficient potting media. Seedlings were: 1) not inoculated; 2) inoculated with WSM 1115; 3) inoculated with SRDI 554; 4) not inoculated and received mineral nitrogen. Plants were managed as described in Drew and Ballard (2010) and shoot dry weight determined 38 days after inoculation.

Results and Discussion

Field Performance

All of the SU tolerant breeders' lines had similar performance to the mid-season cultivar Jester and we have presented the line chosen for release as a cultivar relative to cultivars in Table 1. The similar performance of breeders' lines and Jester was expected as we backcrossed the SU tolerance into barrel medic six times and the two barrel medic parents ("*tap*" and Jester) we used are closely related. The close relationship between "*tap*" and Jester allowed us to focus our selection on the desired traits (i.e. SU tolerance, BGA and SAA resistance) and limited selection/evaluation was required for field performance. These results confirm the findings of Peck and Howie (2012) that SU tolerance can be transferred from the strand medic Angel into a barrel medic background without any penalty in field performance. Early stage seed increase of Z2504 has commenced in 2015. The new cultivar will enable farmers in medium rainfall areas to successfully grow barrel medic pastures in the presence of SU herbicide residues resulting from applications to prior crops.

Table 1: Field performance of SU-tolerant barrel medic line Z2504, various medic and subclover cultivars at Mallala (Mal.) and Temora (Tem.), drymatter (DM1 15/8/2012, DM2 12/10/2012 & 9/10/2012), Regeneration (Regen) drymatter scored 13/8/2013. * scaled so maximum is 100.

Cultivar/line	Species	DM1*	DM2*		Seed yield (kg/ha)		Regen.*
		Tem.	Mal.	Tem.	Mal.	Tem.	Tem.
Z2504	*M. truncatula*	86	100	77	434	1170	61
Jester	*M. truncatula*	84	89	67	549	923	50
Paraggio	*M. truncatula*	81	61	74	493	1148	68
Sephi	*M. truncatula*	81	81	49	490	1124	76
Caliph	*M. truncatula*	84	81	58	587	1153	47
Sultan-SU	*M. truncatula*	81	71	51	680	982	56
Scimitar	*M. polymorpha*	100	68	100	1037	792	100
Antas	*T. sub. ssp. brachycalycinum*	40		51		420	55
Mintaro	*T. sub. ssp. brachycalycinum*	35		48		275	74
Campeda	*T. sub. ssp. subterraneum*	39		9		0	29
Losa	*T. sub. ssp. subterraneum*	55		21		78	32
l.s.d. (P=0.05)		12	22	22	93	163	18

At the acidic site Temora, ranking of species from high performance to low was: burr medic; barrel medics; subclover ssp. *brachycalycinum*; and subclover ssp. *subterraneum*. This was despite the potential seed yield of burr medic at Temora being reduced by an estimated 40% by seed wasps (based on pod yields and expected harvest index). Barrel medic and subclover entries were unaffected. Burr medics in conjunction with new acid tolerant strains of rhizobia are well adapted to mildly acidic soils (Revell and Ewing 1989) and their high performance at this site supports this. Dear and Jenkins (1992) at the same Temora site (1985-1988) found that barrels medics had similar drymatter performance as subclover but barrel medics had greater seed pools. The higher seed yield in medics and subclover ssp. *brachycalycinum* that we observed may be due to the relatively dry growing season restricting seed set of ssp. *subterraneum*. In their natural habitat ssp. *subterraneum* and ssp. *brachycalycinum* often coexist but ssp. *brachycalycinum* are later flowering as they do not require moist soils to set seed (Piano *et al*. 1993). Scott and Brownlee (1976) report that in dry springs, barrel medics were still able to set seed but that subclovers were severely restricted which in turn results in poor drymatter production in subsequent years. Little *et al*. (1992) report that barrel medics perform well in mildly acidic soils with low levels of aluminium. In spite of these historic papers reporting good performance of medics in mildly acidic soils, many farmers with these soils restrict themselves to growing subclover. Medics have higher levels of hardseed than subclover which aids their persistence. Climate change predictions of a drier climate and greater frequency of droughts suggests that farmers with mildly acidic soils could consider sowing medics when they next sow an annual legume.

Subclover ssp. brachycalycinum is usually recommended for sowing on neutral to alkaline soils (Nichols *et al*. 2013) however this overlooks several reports (Boschma *et al*. 2011 pH 5.1-5.6; Dear *et al*. 2003 pH 4.6-5.4; Dear *et al*. 2007 pH 4.8-6.0) of ssp. *brachycalycinum* outperforming ssp. *subterraneum* on mildly acidic soils. Our results, along with the above reports, suggest that *brachycalycinum* cultivars (in addition to *Medicago* spp.) have a greater role to play on mildly acidic soils.

Symbiotic compatibility

The short-listed breeders lines were highly effective at fixing nitrogen, resulting in similar amounts of shoot dry weight as the mineral nitrogen treatment (Fig. 1). Well nodulated annual medic pastures fix nitrogen which benefits the other pasture components and/or following cereal crops.

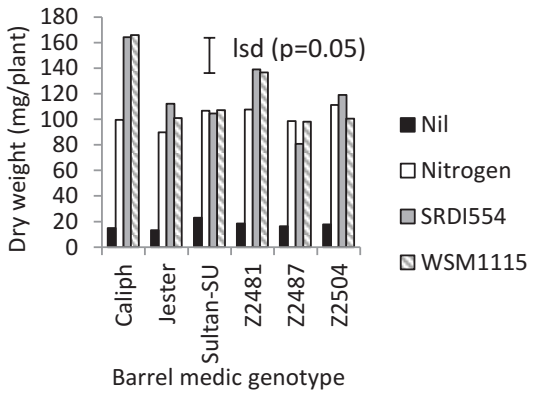

Fig. 1: The SU tolerant breeder's lines (Z2481, Z2487 and Z2504) and cultivars all developed effective symbioses with *Sinorhizobium medicae* strains WSM 1115 and SRDI 554.

Molecular marker

A diagnostic molecular marker for SU tolerance (Oldach *et al*. 2008) will be used to identify homozygous SU tolerant plants. The use of the marker will allow us to efficiently identify homozygous SU tolerant plants without the need to collect pods from individual plants and then conduct progeny screening. The marker will also enable the cultivar to be available to farmers one year earlier. Nichols *et al*. (2012) report that no pasture legumes have been released globally as a result of marker assisted selection. This suggests that Z2504 will be one of the first pasture legume cultivars that have used marker assisted selection in its development.

Conclusion

The mid-season line Z2504 has tolerance to SU residues and performed well at both an alkaline (pH 7.7_{w}) and an acidic site (pH 4.8_{CaCl2}) and will be released as a cultivar. In 2015 we will use a diagnostic marker for SU tolerance and begin the seed increase process. The molecular marker will allow us to

identity homozygous SU tolerant plants more efficiently than progeny testing and will ensure the cultivar is commercially available one year earlier. At the acidic site burr medic, barrel medics and subclover ssp. brachycalycinum all out-performed the traditionally grown ssp. subterraneum. With climate change predictions suggesting an increase in the frequency of dry springs the ability of medics and ssp. brachycalycinum to set seed with dry soils will be increasingly valued by farmers.

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Near-term pasture growth rate forecasts: which method works best?

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Abstract
Knowledge of near-term pasture growth rates helps livestock farmers with important management decisions, particularly feed budgeting. Here we contrast three approaches for generating three-month pasture growth rate forecasts using a biophysical plant model. Two methods were based on statistical growth rates simulated using either historical climate data or historical data having Southern Oscillation Indices (SOI) matching those of the current month. The third method accounted for current earth and ocean measurements using dynamic climate outlooks from the global circulation model POAMA. We used twelve months of measured pasture growth rates to calibrate the model, and then contrast each forecasting method over several three-month periods using empirical cumulative distribution functions. In general, dynamic forecasts from POAMA had the greatest skill and reliability in forecasting the near term (30 day) pasture growth rates, indicating that the use of current climate outlooks and recent weather measurements are more reliable than using methods based on historically measured data. This work is being developed into a graphical-user interface that will allow farmers to view a near -term pasture growth rates forecast using an online tool.

Key Words
Pasture growth forecasting, growth rates, DairyMod, Seasonal climate forecasts

Introduction
Effective pasture management and pasture consumption are key determinants of dairy farm business success. There is an ongoing need to establish approaches to monitoring changes in variables relating to effective pasture management such as pasture growth rate, pasture biomass and leaf appearance rate. Such approaches often rely on direct measurement. While historical regional pasture growth rate data provides some knowledge about likely growth rates for a given location, both inter- and intra- annual variation lead to a higher degree of uncertainty in these predictions. Biophysical models are an effective means of generating such information. Several biophysical models have been developed for the Australian and New Zealand grazing industries, including DairyMod (Johnson et al. 2008) and APSIM (Keating et al. 2003). The performance of DairyMod has been extensively evaluated (Cullen et al. 2008; Rawnsley et al. 2009) and the model can realistically simulate monthly pasture growth and seasonal yields of ryegrass based pastures across a range of soil types and pasture management options. Whilst such models have been used to generate regional information, little effort has been devoted to using biophysical models to produce short-term forecasts of pasture growth rates. The successful application of models such as DairyMod depends on both the ability of the model to accurately simulate the edaphic and biotic factors influencing pasture/crop growth as well as the accuracy of the forecast weather used within the biophysical model.

The aim of this study was to compare and assess the accuracy of simulated pasture growth forecasts produced using historical weather records, Southern Oscillation Index (SOI) phases in concert with historical records and the Bureau of Meteorology global circulation model POAMA (Predictive Ocean Atmospheric Model for Australia, see http://poama.bom.gov.au/).

Methods
A study site was selected on a commercial rain-fed dairy farm at Woolnorth (40.68°S, 144.72°E), north-western Tasmania. The site was an established perennial ryegrass (*Lolium perenne*) pasture. The soil was fine loamy sand and soil tests to a depth of 75mm were undertaken in March 2013 and a basal dressing of fertiliser applied to correct any nutrient limitations. The experimental site was sprayed with Agritone® (a.i. MCPA, present as dimethylamine salt, 750 g/L) at an equivalent rate of 1.5 L/ha to remove existing broad-leaf weeds in February 2013. Fences were constructed around the experimental site, prior to which pastures were grazed by dairy cows. On monthly intervals, four 4 m^2 quadrats were defoliated to a residual of ~1.4 t

DM/ha, consistent with prior grazing by cattle. Nitrogen fertiliser was applied to the experimental site as urea (46% N) at 60 kg N/ha following each defoliation event to maintain soil N at levels optimal for ryegrass growth. Quadrat biomass was freshly weighed and a subsample of approximately 500g dried in a forced-draught oven at 60°C for at least 48 hr, allowing determination of pasture dry matter (DM) and monthly growth rates.

Simulations were conducted using DairyMod (version 4.9.6). Simulations were designed to mimic experimental management and site characteristics as closely as possible, including harvest residuals, cutting and fertilisation dates, as well as soil properties. The climate data used in model parameterisation was Patched Point Data obtained from the SILO database (http://www.longpaddock.qld.gov.au/silo/, Jeffrey et al 2001). Pasture forecasts were simulated using DairyMod with climate data from three sources; historical (HIST, derived from the SILO data described above), the Southern Oscillation Index, (SOI-historical), which was derived from a subset of SILO data, and POAMA (derived from GCM seasonal outlooks and calibrated using hindcasts and climatologies of historical weather). Pasture forecasts from the three climate data sources were derived for a period of one, two, and three months from the beginning of the forecast date. The SOI-Historical simulations were produced using a subset of historical climate data using analogue years in accord with the current SOI phase. In contrast to the HIST data set (which used recent climate data from 1994-2013), SOI years were sourced from climate data between 1901 and 2013 due to the need to select compatible SOI phases for the month starting the forecast. The POAMA climate data was simulated and the ranges of one to three months from forecast date were used to produce the forecasts.

Following parameterisation, model performance was evaluated using a range of model evaluation statistics based on the work of Tedeschi (2006). The relationship between modelled and observed biomass was compared against a 1:1 line and statistically by calculating the mean bias, R^2, R, model efficiency, mean prediction error, variance ratio, bias correction factor and the concordance correlation coefficient. To contrast each forecasting method by forecasting period we compared the empirical median-adjusted cumulative distribution functions (CDF) with observed growth rates. In total there were ten growth rate forecasts for the start of each month: three forecasting approaches for each 30, 60 or 90-day forecast duration as well as a tenth forecasting method that used the historical (1994-2013) simulated value for each month. To contrast and assess forecast skill we subtracted the monthly median for each method and then used the Ecdf function in the Hmisc R library to obtain empirical CDFs. This procedure eliminated position differences so that possible shape and spread differences were comparable. For statistical inference a bootstrapped Kolmorogov-Smirnov test was used. All analyses were undertaken using R.version 3.0.

Results

Simulated pasture growth rates were mostly within one standard deviation of the observed mean growth rate (Fig. 1).

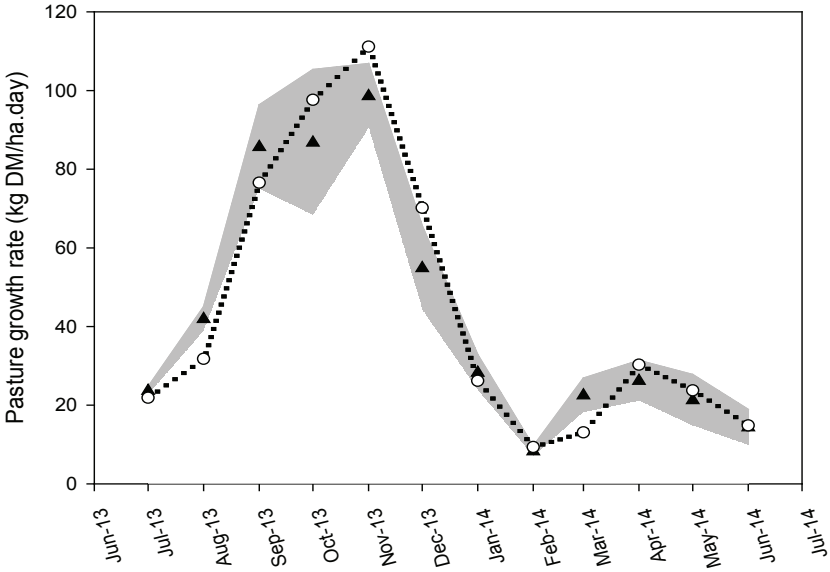

Figure 1. Observed (▲) and modelled (○) perennial ryegrass mean daily growth rates ± one standard deviation (grey shaded) at Woolnorth for the period July 2013 to June 2014.

Evaluation statistics also indicated that model calibration was acceptable. The overall observed and simulated mean pasture growth rate were both ~43 kg DM/ha.day. The coefficient of determination, mean prediction error, variance ratio and bias correction factor were 0.95, 0.19, 0.89 and 0.99, respectively. Overall, the evaluation statistics and the comparison between modeled and observed pasture growth rates indicate that the model adequately simulated pasture growth rates under rain-fed conditions with an acceptable degree of confidence.

In comparing the CDFs of the three forecasting methods for each of the forecasting periods to the observed (Figure 2a-c) only the POAMA 90 day forecast had a significantly ($P < 0.05$) different CDF to the observed. The historical (1994-2013) simulated median was also found to be consistent with observed (Figure 2d).

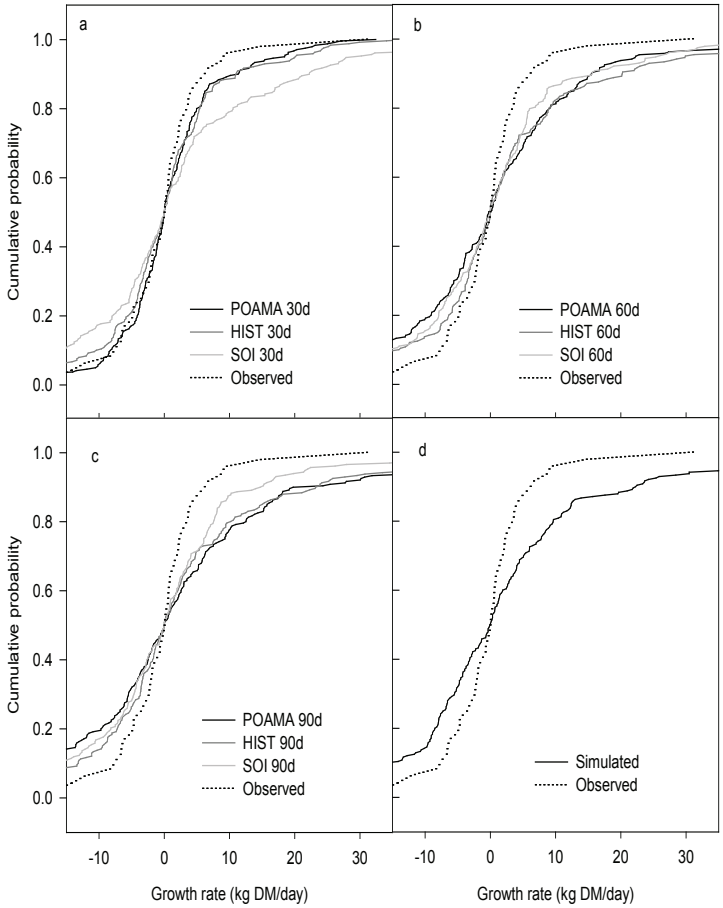

Figure 2. Empirical CDFs for monthly median-standardised data. Measured CDFs are shown as dotted lines. The CDFs for each method (POAMA, HIST and SOI) are solid lines for the 30 day (a), 60 day (b) and 90 day (c) forecast period. The historical simulated is shown in (d). Observed represents measured values.

The lowest Kolmogorov-Smirnov (KS) statistic was found with the 30 days forecast of POAMA (KS = 0.10) followed by the 30 days forecast of HIST (KS = 0.13). All other forecast methods by forecast periods had a KS statistic greater than 0.15 (Table 2). This statistic indicates that the highest level of consistency between the observed median adjusted pasture growth occurred with the 30 day forecast period using POAMA, followed by the 30 day forecast using historical data (HIST.30).

Discussion

The strong agreement between modelled and observed indicates that DairyMod has been well designed to simulate ryegrass production in the temperate region, provided calibration is appropriately performed. This is consistent with other reported studies using DairyMod (Cullen et al. 2008; Rawnsley et al. 2009). The application of such models has not been widely used for developing regional forecast information. This study has addressed this limitation and the forecasting approach undertaken here has produced encouraging results, particularly for short-term forecasts (e.g. one month from the forecast date). As the model is able to effectively simulate actual observed pasture growth rates, the ability to forecast pasture growth is critically

Table 1. Kolmogorov-Smirnov (KS) statistic and P value comparing the observed data to the prediction for median adjusted pasture growth value for each forecasting method, period (30, 60 or 90 days) and the historical simulated.

Method.period	KS	P values
SOI.90	0.16	0.23
SOI.60	0.18	0.15
SOI.30	0.18	0.14
HIST.90	0.19	0.12
HIST.60	0.17	0.19
HIST.30	0.13	0.48
POAMA.90	0.22	0.04
POAMA.60	0.20	0.09
POAMA.30	0.10	0.82
Simulated	0.19	0.12

dependent on an accurate seasonal weather forecast. There was an acceptable level of consistency between the forecast and the observed but generally consistency was better in the ensuing 30 day period, followed by the 60 and 90 day periods. The SOI-historical climate data appeared to have the lowest forecast skill, particularly the closer to the forecast date compared with the historical and POAMA data. In comparing each monthly forecast (data not shown) the forecasting skill was lower throughout summer and early autumn and higher from May through to October, the latter a period which experiences a higher reliability of rainfall events and lower daily variations in temperature. Overall results were encouraging, particularly for near-term forecasts of 30 days using POAMA data. At 60 and 90 days, the consistency between the forecast and observed pasture growth rate declined. Although the consistency of the 60 and 90 day forecast using POAMA was less than that of the historical and SOI approach continued improvement in the physics equations inherent to POAMA forecasts should enhance the pasture forecasting capability. We view the ability to provide reliable three month weather forecast to be highly important for extending and enhancing the approach reported here. This will ultimately lead to an autonomous framework which can deliver consistent and accurate real time forecast pasture growth information.

Acknowledgements

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Adapting irrigated and dryland farming systems to climate change and extreme weather events: is simplification or intensification more effective?

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Abstract
Past research has advanced our knowledge of climate change impacts on grassland production and crop yields, yet the resilience of whole farm systems to climate change remains to be quantified. Here we examine how climates in 2040 influence the production and animal feed requirements of dryland and irrigated dairy farms in southern Australia, then contrast the resilience of adaptations that simplified or intensified baseline farm inputs and management. The effects of farm system simplification or intensification on seasonal pasture growth rates in mitigating adverse effects of climate change were small. Relative to historical climates, annual pasture production and livestock pasture consumption in 2040 on dryland farms decreased by ~11% under baseline management or intensification, whereas adaptations that simplified systems resulted in little change in pasture production, pasture consumption or the need to purchase hay. The impact of climate change on annual pasture production and livestock pasture consumption of irrigated farms was less than that for dryland farms. In 2040 the need to purchase hay on the irrigated farm increased by 41% or 104% under baseline management or farming simplification, whereas purchased hay requirement under both historical and future climates under intensification was similar. Collectively these results suggest that the most effective adaptations in mitigating the effects of climate change on dryland and irrigated farms were simplification and intensification, respectively, but future work should address how climate and adaptation scenario influence profitability and risk.

Key words
Extreme events, adaptation, dairy farm, sustainable intensification, climate change, pasture, milk

Introduction
While the impacts of climate change on crop and pasture production have been scrutinised for some time, knowledge of climate change impacts on whole farm production is in its infancy. A recent review highlighted the dearth of work examining the influence of climate variability on the timing of climatic stresses on pasture growth, and how such effects cascade through whole farm systems to impact on livestock production (Thornton *et al.* 2014). There is yet a paucity of information detailing how dairy farms might adapt to climate change. While there have been some reductionist studies documenting the effect of a single factor on production (e.g. stocking rate or pasture species), literature on the impacts of adaptations at the whole farm level are rare. Studies applying a more holistic approach by examining adaptations that incorporate simultaneous changes in several variables are even more scarce.

The present study was conducted as part of a larger multidisciplinary research project currently in progress (http://www.dairyingfortomorrow.com/uploads/documents/file/DBFFC/Dairy%20Business_NOV %20A4% 20Newsheet_FINAL_1114.pdf). Two whole farm adaptations to climate change were designed for a dryland and an irrigated case study farm, and a new method was developed for generating future climate data containing increased frequencies of extreme events (Harrison *et al.* 2015). Farm systems were simplified or intensified relative to baseline management under current climates, with simplification reducing fertiliser inputs, herd size and purchased feeds, and with intensification increasing fertiliser applications, herd size, purchased feeds, and/or animal liveweight (Table 1). The purpose of this study was to determine whether farm system simplification or intensification served as a more effective adaptation to climate change.

Methods
Simulations were conducted using a whole farm model for a dryland dairy farm in Victoria (Moe; 38.17°S, 146.27°E) and for an irrigated farm in Tasmania (Wynyard; 41.00°S, 145.72°E). Baseline farm data and reports (monthly milk production, supplementary feed use etc.) were used to parameterise the model. Adaptations were designed iteratively by project teams and were intended to either simplify or intensify farm.

Table 1. Data used to simulate the impacts of historical and future climates (2040) for two locations for case study farm management (baseline) and for adaptations that simplified or intensified baseline systems.

	Baseline		Simplify		Intensify	
Moe, Victoria	**Historical**	**2040**	**Historical**	**2040**	**Historical**	**2040**
Nitrogen fertiliser (kg N/ha/year)	189	172	120	150	224	203
Adult milking cows	352	352	200	200	500	500
Cow liveweight (kg)	475	475	475	475	550	550
Stocking rate (cows/ha)	3.2	3.2	1.9	1.9	4.5	4.5
Calving time	Spring	Spring	Autumn	Autumn	Split[A]	Split[A]
Whole farm area (ha)	175	175	175	175	175	175
Wynyard, Tasmania						
Nitrogen fertiliser (kg N/ha/year)	251	236	150	143	267	257
Adult milking cows	450	450	350	350	600	600
Cow liveweight (kg)	500	500	500	500	500	500
Stocking rate (cows/ha)	3.0	3.0	2.3	2.3	4.0	4.0
Calving time	Winter	Winter	Winter	Winter	Winter	Winter
Whole farm area (ha)	150	150	150	150	150	150
Irrigated area (ha)	100	100	100	100	150	150
Irrigation amount (ML/ha)	2.05	2.17	2.05	2.17	2.07	2.19

[A] Fifty percent of the herd calved in spring and 50% calved in autumn

systems (Table 1). Climate data from 1975 to 2013 were sourced from http://www.longpaddock.qld. gov.au/silo. A new approach was developed for simulating 2040 climate data that contained longer drought, more intense rainfall events and increased severity of heat waves relative to historical climates (Harrison et al. 2015). The approach incorporated both the Representative Concentration Pathways 8.5 projection for gradual climate change as well as our new method of generating increased frequencies of extreme events. At Moe, average annual rainfall decreased from 940 mm historically to 840 mm in 2040; at Wynyard historical rainfall was reduced from 995 mm to 932 mm in 2040. At both locations the decline in rainfall was relatively uniform across months. Monthly average minimum and maximum temperature at both sites increased by ~0.5°C and ~1°C respectively, with the greatest increases between January and April. Atmospheric CO_2 concentrations were set at 380 ppm and 490 ppm for historical and future climate data, respectively.

Results

Pasture growth rates on the dryland farm

Higher temperatures in 2040 elevated pasture growth rates in winter and spring, but growth rates in other seasons were reduced relative to historical climates due to the combination of more heat waves and longer drought periods (Figs 1a-c). Under historical climates, both adaptations reduced peak growth rates in spring relative to baseline management (dashed curves in Figs 1a-c). Climate change reduced annual pasture production of the baseline and intensification scenarios by 11% and 9% respectively, but had minimal effect on annual production under the simplification scenario (data not shown).

Pasture growth rates on the irrigated farm

Climate change increased growth rates on the irrigated farm in winter but reduced growth rates in other seasons (Figs 1d-f). Seasonal growth rates under simplification were relatively flat throughout the year, whereas growth rates under intensification increased relative to baseline management in spring, summer and autumn due to the combination of higher temperatures, greater nitrogen fertilisation and greater farm area under irrigation (Table 1). Despite large differences in annual pasture production under historical climates in each scenario (15.5, 11.1 and 17.9 t DM/ha/year for the baseline, simplification and intensification scenarios, respectively), the effect of climate change on annual pasture production was small in all management scenarios, averaging -2%.

Influence of climate change on pasture consumption and purchased feed at the dryland site

For the baseline and intensification scenarios, milking area pasture consumption at the dryland site was reduced by ~11% relative to the same scenario under future climates, whereas consumption remained relatively stable under climate change in the simplified farm system (7.8 t DM/ha/year, Table 2).

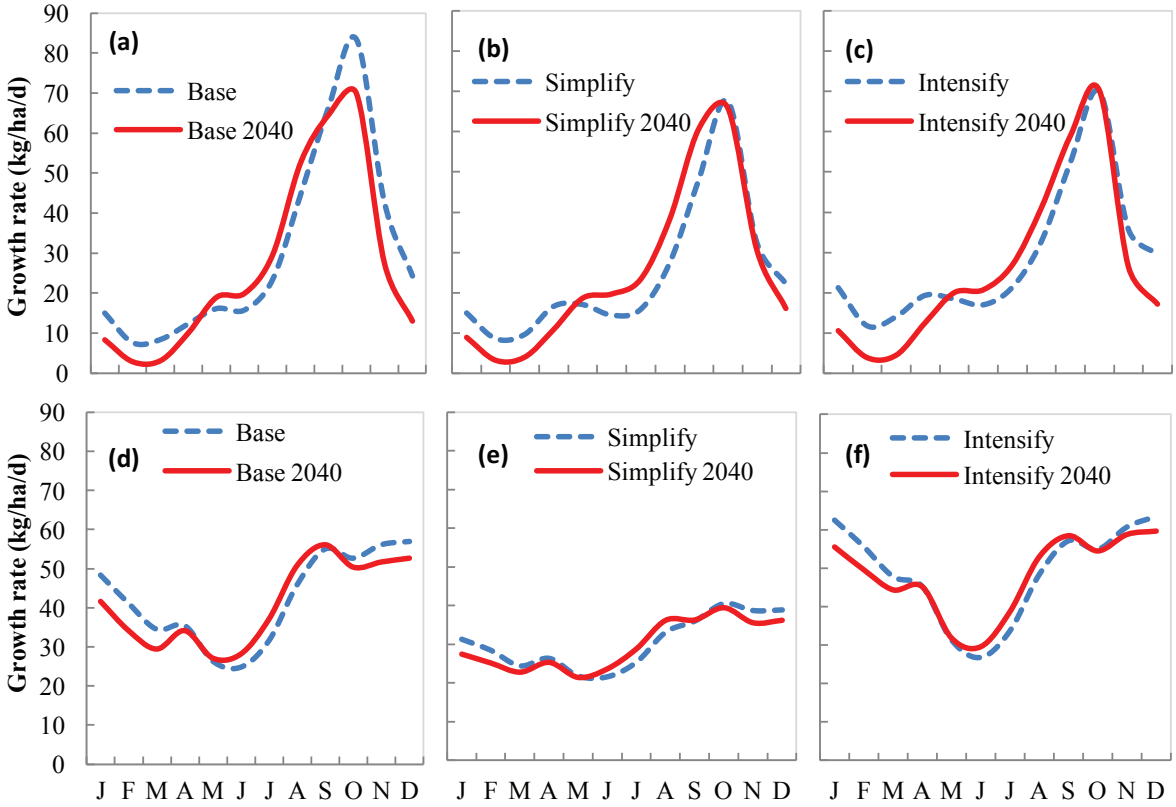

Figure 1. Average monthly pasture growth rates for dryland (Moe; a-c) and irrigated (Wynyard; d-e) case study dairy farms under historical and future climates. Left, center and right columns show growth rates for the baseline farm, and the simplification and intensification adaptations, respectively.

In order to maintain cow liveweight and milk production due to reduced pasture growth in 2040, the need to conserve dry fodder increased. Under future climates hay/silage conservation at the dryland site increased by 45%, 21% or 16% in the baseline, simplify and intensify cases, respectively, indicating that both adaptations

Table 2. Biophysical results simulated using historical and future (2040) climate data. Values are 38 year averages for baseline management and for adaptations that simplified or intensified each baseline system.

	Baseline		**Simplify**		**Intensify**	
Dryland farm (Moe, Vic)	**Historical**	**2040**	**Historical**	**2040**	**Historical**	**2040**
Milk production per animal (kg MS[A]/cow)	395	392	449	448	531	515
Milk production whole farm (kg MS/farm)	139,128	138,095	89,705	89,591	265,747	257,721
Grazed pasture consumed (t DM[B]/cow)	2.8	2.3	3.7	3.4	2.2	1.9
Milking area pasture consumed (t DM/ha)	9.0	8.1	7.8	7.8	9.7	8.6
Grain consumed per animal (t DM/cow)	1.1	1.1	0.5	0.5	2.0	2.0
Grain purchased (t DM/farm)	360	360	100	100	1,000	1,000
Hay/silage purchased (t DM/farm)	240	296	25	14	985	1,037
Hay/silage conserved (t DM/farm)	290	421	344	417	237	275
Irrigated farm (Wynyard, Tas)						
Milk production per animal (kg MS/cow)	496	489	442	434	540	531
Milk production whole farm (kg MS/farm)	223,113	220,205	154,545	152,074	323,752	318,340
Grazed pasture consumed (t DM/cow)	3.6	3.5	3.6	3.5	3.3	3.2
Milking area pasture consumed (t DM/ha)	12.4	12.1	11.2	10.9	13.6	13.2
Grain consumed per animal (t DM/cow)	1.1	1.1	0.5	0.5	1.4	1.4
Grain purchased (t DM/farm)	473	473	158	158	810	810
Hay/silage purchased (t DM/farm)	239	337	124	253	853	877
Hay/silage conserved (t DM/farm)	250	236	425	412	74	75

[A] Milk solids; BDry matter

reduced the ability to conserve home-grown feed under climate change. The need to purchase hay/silage in future climates increased in the baseline and intensification scenarios by 52-56 t DM/year, whereas there was little need to purchase dry fodder under 2040 climates in the simplification scenario.

Influence of climate change on pasture consumption and purchased feed at the irrigated site
Pasture consumption in 2040 at the irrigated site dropped by 2-3% regardless of adaptation scenario due to 6% greater irrigation requirement (Table 2). The impact of climate change on hay/silage conservation under baseline management at the irrigated site was small but increased the need to purchase dry fodder by 41% or 104% for the baseline and simplification scenarios, respectively (Table 2).

Discussion

The goal of this study was to determine whether simplification or intensification of current management and inputs on real dairy farms would serve as a more effective adaptation to climate change. Results indicate that the outcome depends on both the metric used to assess effectiveness as well as whether farms were rainfed or irrigated. If the metric used to assess effectiveness was seasonal pasture growth rates averaged over the longer term, then neither adaptation was more effective, since both simplification or intensification differed little from baseline management (Fig. 1). However, if the metric used to assess effectiveness was annual pasture production or livestock pasture consumption, then at dryland sites adaptations that simplified farming by reducing purchase of hay and silage, stocking rates and pasture inputs appeared the most prospective option. In 2040, annual pasture production on the dryland farm under the simplified adaptation was similar to that produced historically, whereas consumption and pasture production for either the baseline or the intensified adaptation was reduced by around 10%. In contrast to the dryland farm, climate change had relatively small influence on annual pasture production, grazed pasture consumption or conservation of hay/silage on the irrigated farm, irrespective of whether the farm was under baseline management or was adapted by simplification or intensification. If effectiveness was gauged by the ability of an adaptation to alleviate the need to purchase hay, then farming intensification would appear to be the most beneficial option.

This study is currently in progress and has not yet assessed economic aspects, which from an enterprise perspective is likely to be one of the most important issues in assessing effectiveness of different adaptations to climate change. Further, we have not yet quantified risk associated with production or cash flows, which would likely differ across adaptations given that the intensification system assumed significant capital investment in major machinery and equipment.

Conclusions

Climate change reduced pasture availability and increased the need to purchase hay on the dryland farm under adaptations that intensified production; in contrast, adaptations that simplified dryland farm inputs and management were less vulnerable to climate change. Climate change had little influence on pasture production on the irrigated farm, other than a small increase in the irrigation requirement, though simplification increased the need to purchase hay. This study suggests that the most effective adaptations to climate change are farm system simplification of dryland farms and intensification of irrigated farms. Future work should consider economic implications of different adaptations such as silvopasture, which has proven more productive and more profitable than baseline systems for both dairy and beef production systems (Agri Benchmark 2015; Harrison *et al. 2015b).*

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Can modelled soil moisture with the Southern Oscillation Index predict poor spring pasture production?

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Abstract
Better early predictions of low spring pasture production would be of great value to southern Australian broad acre grazing farmers. Three Victorian livestock farm case studies were used to investigate whether the use of modelled soil water, combined with the Southern Oscillation Index (SOI), could provide early and accurate prediction of poor spring pasture production. Case studies were located in Central Victoria at Woodend (W) and Baynton (B), and North East Victoria at Seymour (S). Climate data from the last 120 years (1890-2010), obtained from the closest meteorological station, were used for each farm to model total spring pasture production and total soil water (TSW) using the GrassGro™ model. A combination of TSW on the first day of September and the SOI for August were used to predict spring pasture production for all paddocks on each farm. TSW with the SOI accounted for 75.6 percent of the variance, where the previous year's spring pasture production was included. Eighty eight percent of years that had low decile TSW on September 1st and SOI at or below -8 were followed by very poor springs (pasture production in the lowest two deciles) and only 4% of years had above average springs. Providing farmers with localised up to date modelled soil water, together with the SOI, may provide acceptable accuracy in predicting most years of low spring pasture production, enabling early tactical decisions to reduce the impacts on the landscape and financial returns.

Keywords
Decision support system, GrassGro modelling, pasture production, tactical decisions.

Introduction
Australian farmers deal with some of the most variable climate in the world (Bureau of Meteorology BOM website) which has significant impact on farming profitability and sustainable grazing systems (Ash, 2007). The ability to reduce the impact of poor seasons relies on early and good information to make effective tactical decisions. Vizard and Anderson's (2009) analysis of seasonal predictions using the phases of the Southern Oscillation Index (SOI) reported that the use of the SOI as a forecasting tool was seldom high but had some value in predicting spring rainfall in eastern Australia. Cullen and Johnson (2012) modelled soil water content at Hamilton, SW Victoria, and concluded that modelled soil water had the potential to predict pasture growth at the most variable times of the year (autumn and spring). A combination therefore of modelled stored soil water at the end of winter and the SOI as a predictive rainfall for spring could be considered as a potential model for predicting spring pasture production, particularly in years of low pasture growth.

The aim of this study was to investigate whether modelled soil water at the end of winter in combination with the SOI could provide early and accurate prediction of low spring pasture production on case study farms in Central and North East Victoria. Low spring feed production was considered to be when spring pasture production was in the lowest two deciles over the 120 year period studied.

Method
Three case study farms were selected to represent areas with known high rainfall and land class variability, as well as farmers with reasonable records for validation of farm production. Farms were located in Central Victoria at Woodend (W) and Baynton (B), North East Victoria at Seymour (S) with average annual rainfalls (1970-2010) of 772mm, 661mm and 612mm respectively. Each farm had at least two distinct land classes, soil and pasture types. The pastures were improved perennial grasses (phalaris or ryegrass) and sub clover on the arable land and unimproved grasses (annual grasses and native perennial grasses) and sub clover on non arable country.

Farms were modelled using the GrassGro™ simulation program (Moore *et al.* 1997) using 120 years (1890 - 2010) SILO climate data (Jeffrey et al,.2001) from the closest weather recording station. Initially, farms were

modelled with existing livestock enterprises and stocking rates for validation. Enterprises run on farms included superfine merinos (self replacing and wethers), fine wool self replacing merinos, Coopworths and composite self replacing ewes. The model was validated using historical production records. Whilst GrassGro™ could not fully mimic production performance as achieved on farm, (partly because stock numbers are kept constant across years in GrassGro™), the outputs were considered adequate in predicting the range and averages in values for wool cut (per head and per hectare), live weight or carcase sold for prime lamb enterprises, ewe fertility (as number of lambs weaned) and stocking rates.

Stocking rates were set to have a whole farm pasture utilisation rate of close to 40% to equal grazing pressure on each farm. Lambing times were between early July and August, reflecting farm management practices and optimal times estimated in gross margin analyses generated by GrassGro™. Grazing management of the different land classes was set to a flexible grazing of all livestock classes across all land classes, where stock were moved when weight gain could be improved by 10g/head/day. All farms were simulated to run Coopworth self replacing meat sheep as this was considered an enterprise that would be highly responsive to both good and poor seasons.

Estimates of total soil water (TSW) for each land class (as paddock) on each farm on the first day of spring (1st September) for each year between 1890 and 2010 were derived from GrassGro™. The TSW was modelled for each land class to test whether generic modelled soil water for a location or district would be robust enough to cover a range of soil and pasture types in predicting the season. Spring pasture production was estimated for each land class and farm for each year as kilograms of dry matter per hectare grown from 1st September to 30th November, inclusively.

GENSTAT was used to run a generalised least squares model and multiple linear regression analysis of the prediction of spring pasture production over the 120 years studied. Several mixed linear models were tested:

- TSW (1st Sep) and SOI (Aug)
- TSW (1st Sep) and SOI (Aug) plus spring pasture production in the previous year (Tonnage)
- TSW (1st Sep) and SOI (Aug) plus spring pasture production in the previous year (Tonnage) with
- different slope coefficients for TSW and SOI for each paddock
- TSW (1st Sep) and SOI (Aug) plus spring pasture production in the previous year s (Tonnage) plus soil parameters used in GrassGro™ (top and sub soil depth, saturated conductivity in the top and sub soil, root depth).

To further investigate the reliability of predicting poor springs, counts of years that had TSW on the first of spring (September) in the lowest 10 or 20 percentile combined with an August SOI of -8 or lower, were cross tabulated with spring pasture production with low deciles (0.1, 0.2 and 0.5).

Results and Discussion

Over the 120 year time period, using the TSW for the 1st September and the average SOI for August accounted for 71.9 of the percentage variance in predicting spring pasture production over all paddocks studied. Including both TSW and the SOI improved the prediction of spring pasture production over using each variable in isolation. The prediction was further improved to 75.6%, if the spring pasture growth from the previous year was included in the model. There was no improvement by including either paddock differences or soil parameters in the model.

Table 1 shows the accumulated analysis of variance with the TSW for September, SOI for August and the previous year's spring pasture growth (estimated within paddock). Figure 1 shows the observed versus the predicted values for spring pasture production (as pasture yield in Tonnes per hectare) using this model, over all paddocks.

Table1. Accumulated analysis of variance for predicting Spring Feed, including paddock, TSW (Sep), SOI (Aug) and previous spring feed (Tonnes).

Change	d.f.	s.s.	m.s.	v.r.
+ Paddock	6	2742.4	457.1	345.1
+ TSW Sep	1	563.1	563.0	425.1
+ SOI_ Aug	1	43.5	43.5	32.8
+ Prev_Spring feed	1	81.7	81.7	61.7
Residual	823	1090.1	1.3	
Total	832	4520.5	5.4	

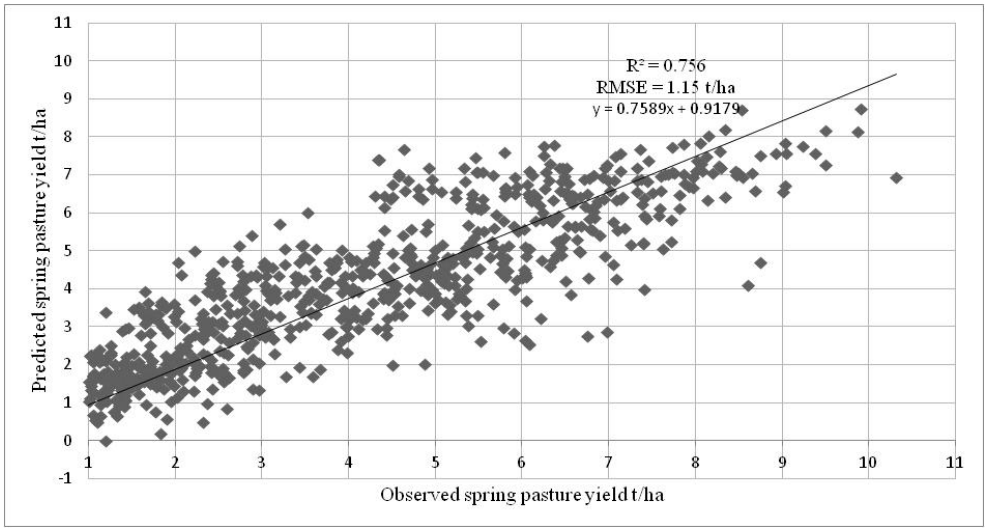

Figure 1. Predicted and observed values for spring pasture production on the 1st of September.

For these case study farms, the analysis showed that modelled soil water and the SOI provided a reasonable prediction of spring pasture production. As GrassGro uses TSW as one of the variables to estimate spring growth, the SOI has provided some predictive rainfall value.

To further investigate the reliability of using TSW and SOI to predict poor spring pasture production, only years that had low values for both TSW and SOI were considered. Years that had TSW on the first of spring (September) in the lowest 10 or 20 percentile combined with an August SOI of -8 or lower, were cross tabulated with spring pasture production with low deciles (0.1, 0.2 and 0.5) to provide counts of years that fell into each quadrant. This was used to consider the reliability of using these values as trigger points make a tactical decision to reduce the impact of low spring pasture production, without the risk of a good spring. For example, if one of the tactics was to sell 30% of stock in early September if there was to be a failed spring, what trigger points would provide adequate confidence that the spring would fail severely.

Over the 120 year period studied, if TSW was in the lowest decile on the 1st September and the SOI was – 8 or lower, there was an 88% probability that spring pasture production would be in the lowest two percentiles with only a 4% chance of being above the median growth.

Whilst the probability of a poor season is high and the chance of a good spring very low, not all failed seasons were predicted using these variables. For example the dry seasons of 2007 and 2008 (at these locations) would not have been identified as the SOI was positive in July and August for 2007 and only -4.3 in July and positive in August for 2008. However, using this trigger point criteria to make a tactical decision on the 1st September, to reduce the impact of a poor spring, may well provide acceptable probability with little risk of making a poor decision.

Conclusion

Including both modelled TSW and SOI improved the prediction of spring pasture growth in the areas studied, than either variable on its own. TSW on the 1st September and SOI for August provided reasonable predictors of spring pasture at the case study locations and with the pasture and soil types modelled.

Using trigger points of modelled TSW in the lowest decile on the 1st September with the SOI for the previous August at -8 or below, there was an 88% probability of a very poor spring, where a very poor spring was defined as spring growth in the lowest 20 percentile for the 120 years studied The chance of above average (median) spring growth was only 4 percent using these criteria. The use of modelled TSW and the SOI could be considered as potential reliable indicators of low spring pasture production to assist livestock farmers in making decisions to reduce the impacts, before the onset of spring. Further research is required to test the predictive relationship over a wider geographical area.

Acknowledgements
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Can seasonal forecast minimise the threats of climate variability to achieve profitable crop-livestock productions in NSW

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Abstract
Reliable seasonal rainfall forecasts with sufficient lead time can play an important role in designing responses to rainfall variability. In this study, seasonal climate forecasts from POAMA (Predictive Ocean Atmosphere Model for Australia) are used to drive the AusFarm (agricultural systems analysis model) biophysical model at two contrasting locations of NSW. The POAMA2 was able to provide good rainfall forecasts started from 1 March at Wagga Wagga for the target months of March-August with statistically significant rainfall anomaly correlation skill (0.30 - 0.44) and 65-72% hit rate. At Narrabri for target months of July-December started from 1 July, the statistically significant rainfall anomaly correlation skill ranges from 0.15 to 0.46 with a corresponding hit rate of 57 to 73%. The good skill of POAMA2 in forecasting the station rainfall variability (even without downscaling) suggests that the forecast may provide value to strategic decision making in a mixed-farming systems. At Wagga Wagga, the forecast distribution of crop yields (wheat, barley, and canola), lamb sale weight and fleece weight for target months starting from March to August show comparable median productivity compared to the observed ones. Likewise at Narrabri, forecast distribution of sorghum, wheat and barley yield is similar to the distribution of observed ones, implying sufficient ability of the POAMA forecast during pre-planting period to make forward farming decisions. Work of this nature, particularly improvement of accuracy of seasonal forecast at a long lead time, has the potential to benefit production and financial performance in a given agricultural system.

Key words
POAMA, seasonal climate forecasts, AusFarm, Simulation, Yield, Fleece weight

Introduction
Agriculture contributes about $15 billion annually to the economy of NSW, and rainfall variability is a major determinant of risk to agricultural productivity and production. Advanced skilful knowledge of climate variability can be utilised by farmers to gear production systems to capture the benefits of high rainfall and avoid losses during drought. POAMA2 (Cottrill *et al*. 2013) is the most advanced forecasting system developed in Australia and it has proven capability to predict the main drivers of Australian climate variations, including predicting the occurrence of El Nino and La Nina 2-3 seasons in advance (Zhao *et al*. 2014) and the Indian Ocean Dipole up to one season in advance (Shi *et al*. 2012), inter-annual variations of the Southern Annular Mode (SAM) up to 2-3 seasons in advance (Lim *et al*. 2013), and the Madden-Julian Oscillation up to 3 weeks in advance (Marshall *et al*. 2011). The forecast model also faithfully reproduces the impact of these climate drivers on regional climate in Australia (e.g., Langford and Hendon 2013), although local level skill varies markedly between regions (Asseng *et al*. 2012). The main objective of this paper is to take some initial steps to develop a seasonal forecasting capability at the localised farm scale, prior to pre-planting crops and making stocking rate decisions at two sites, at a winter and a summer rainfall dominant region of NSW. Initially an assessment of the farm level skill of rainfall forecasts from the POAMA2 is carried out. The rainfall forecasts are then used to simulate crop and livestock productivity at a site in the wheat-sheep belt of Southern and Northern NSW.

Methods
Site: The study focused on two sites in NSW:(1) Wagga Wagga (35°1311' S, 147°3091' E), characterised by austral winter dominant rainfall averaging 571 mm/year and annual mean temperature of 15.8°C and (2)

Narrabri (30°3401' S, 149°7552' E), a summer dominant rainfall region averaging 662 mm/year and annual mean temperature of 19.1°C respectively.

Seasonal Forecasting: We used the POAMA2 seasonal forecast system which consists of coupled numerical models of the ocean, atmosphere and land surface (Cottrill *et al*. 2013). A 33-member ensemble hindcast of POAMA2 starting for each month of January 1981 to December 2013 with 9 target months was available. To generate 33 ensemble predictions, the POAMA2 system uses 3 different versions of the model (Langford and Hendon 2013) to account for forecast uncertainty due to model errors. It uses an ensemble assimilation/ initialization system (Yin *et al*. 2011; Hudson et al. 2013) to obtain 10 realistic but slightly perturbed initial conditions for each model version to account for the forecast uncertainty due to initial condition errors. We assessed the skill of POAMA2 rainfall hindcast starting from 1 March for target months of March, April, May, June, July, and August at Wagga Wagga and hindcast started from 1 July for target months of July, August, September, October, November, and December at Narrabri. The capability of the POAMA2 system is limited by the relatively coarse horizontal resolution of the component models (~250 km horizontal resolution in atmosphere and land surface). This coarse resolution causes some aspects of regional to local climate in Australia to not be well resolved including topographic and coastal effects. In this study, we obtain the daily hindcasts at each site using a bi-linear interpolation of the model output at 250km x 250km to the site location.

Crop-livestock simulation: The AusFarm model (http://www.grazplan.csiro.au) comprising APSIM crop and soil models (Keating *et al*. 2003) and GRAZPLAN pasture and animal management models (Moore *et al*. 2007) was used with both observed climate (SILO patched point; http://www.longpaddock.qld.gov.au/silo/ppd/index) and POAMA2 forecast hindcasts climate data (1981 – 2013) to simulate crops-livestock productivity. Briefly, AusFarm simulates biological and physical processes in a mixed-farming system in response to climate (daily maximum and minimum temperature, rainfall and solar radiation, evaporative demand), in-crop management, livestock enterprises and animal husbandry practices. A mixed crop-livestock farming scenario representative of Wagga Wagga site was developed in AusFarm and crop rotation farming practices in APSIM for Narrabri. Parameters information available in Primefacts (http://www.dpi.nsw.gov.au/aboutus/resources/factsheets/agriculture) pertaining to crop management, sheep enterprises and animal husbandry practices were used in the simulations setup.

Results and Discussion

Despite the coarse model resolution with bi-linear interpolation, POAMA2 was able to provide good rainfall forecasts at these sites. Statistically significant rainfall anomaly correlation skill (0.30 - 0.44) and 65-72% hit rate were obtained at Wagga (Table 1). At Narrabri, the statistically significant rainfall anomaly correlation skill ranges from 0.15 to 0.46 with a corresponding hit rate of 57 to 73%. Although the skill of rainfall forecasts declined as lead time increased, the hit rate remained above 50% (Table 1) for the entire forecast period. The skill of POAMA2 in forecasting these large shifts in rainfall variability suggests there is need to evaluate the utility of these forecasts for improving strategic decision making in mixed-farming at these locations.

Table 1. Significant (P<0.001) correlation coefficients between observed (1981 - 2013) monthly rainfall anomaly and POAMA2 predicted monthly rainfall anomaly started from 1 March and 1 July for different target months in two locations of NSW.

Wagga Wagga			Narrabri		
Target months of forecast	Correlation coefficient	Hit rate	Target months of forecast	Correlation coefficient	Hit rate
March	0.444	72.21%	July	0.333	66.60%
April	0.350	67.51%	August	0.261	63.10%
May	0.319	65.93%	September	0.463	73.20%
June	0.305	65.25%	October	0.329	66.50%
July	0.334	66.72%	November	0.360	68.00%
August	0.297	64.84%	December	0.147	57.40%

A first step is to examine how well simulated crop and livestock yields driven by the climate forecasts capture those simulated using climate observations. Simulated crop and livestock production show considerable temporal variability in the performance over the historical 33 years (Figs. 2 and 3).

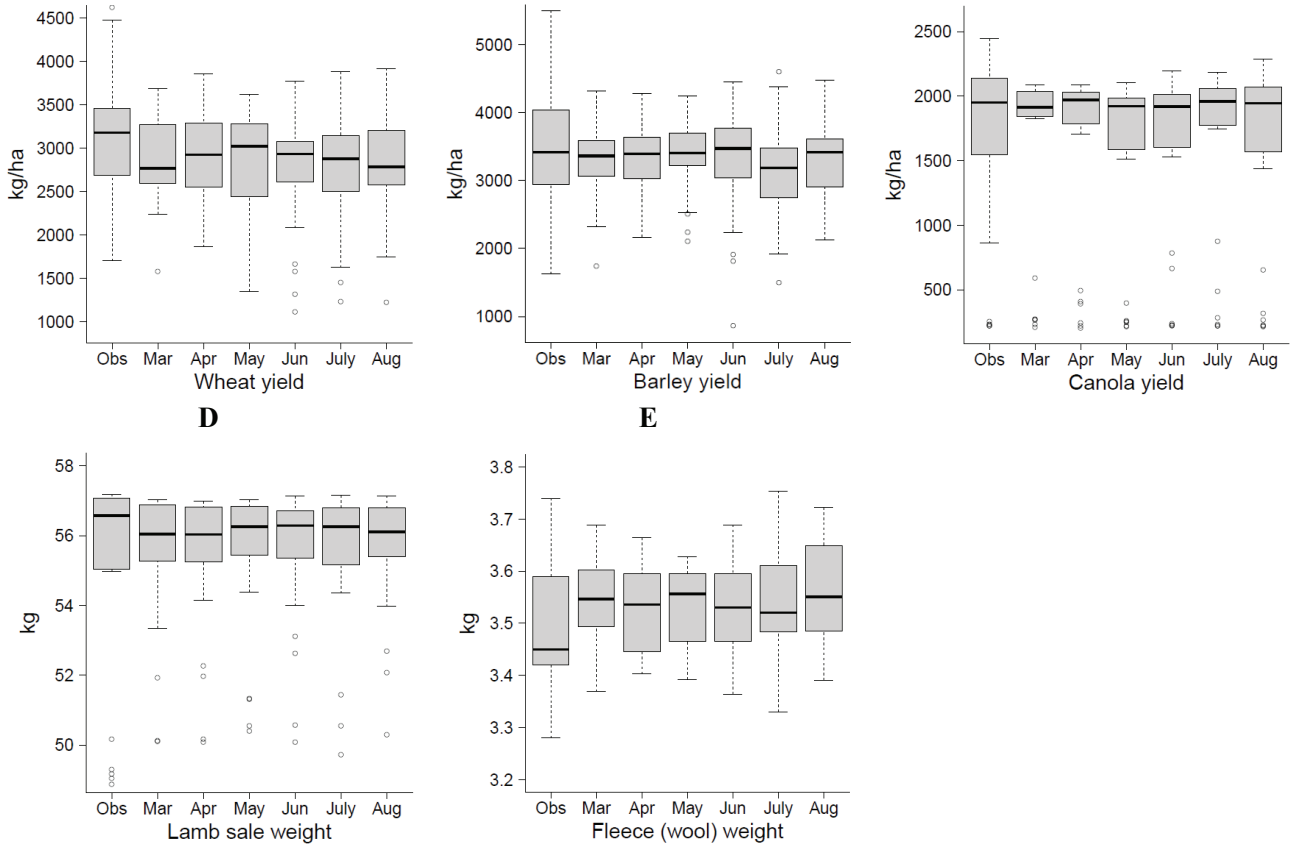

Figure 2. Relative frequency (%) distributions of simulated crop yield (A, B and C), lamb sale weight (D) and wool weight (E) in boxplots at Wagga Wagga. Obs represents yearly crops yield, lamb sale weight and wool weight simulated by observed climate (1981 - 2013). Mar, Apr, May, Jun, and Aug denote yearly crops yield, lamb sale weight and wool weight simulated by POAMA2 climate hindcasts started from the first day of March, April, May, June, July and August, respectively. The POAMA2 hindcasts comprise of ensemble mean of 1089 years (33 x 33).

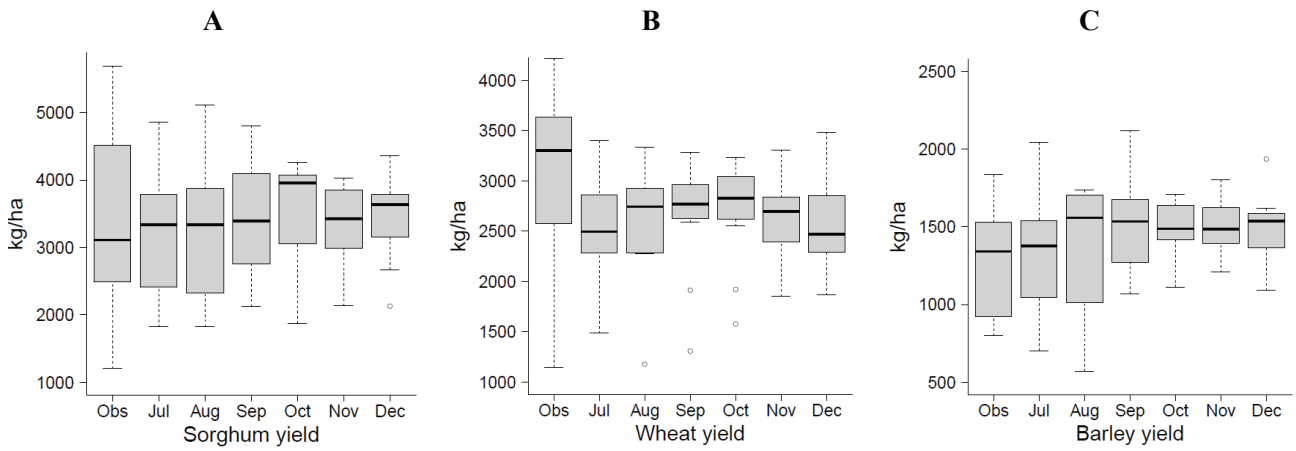

Figure 3. Relative frequency (%) distributions of simulated crop yield (A, B, and C) in boxplots at Narrabri. Obs represents yearly crop yield simulated by observed climate (1981 - 2013). Jul, Aug, Sep, Oct, Nov, and Dec denote yearly crops yield simulated by POAMA2 climate hindcasts started from the first day of July, August, September, October, November, and December, respectively. The POAMA2 hindcasts comprise of ensemble mean of 1089 years (33 x 33).

In Wagga Wagga, the forecast distribution of wheat, barley, canola, lamb sale weight and fleece weight show comparable median productivity to the observed ones for all forecasts started from March to August, respectively. In general, the inter-quartile dispersion of forecasted crops yield, animal weight and fleece

weight is smaller than the observed climate. At Narrabri, forecast distribution of sorghum, wheat and barley yield (Fig. 3) started from July to December is similar to observed climate. These results imply sufficient ability of POAMA forecast during pre-planting period to make forward farming decisions. The initial analysis results in this study confirm what has been found in more in depth broader scale evaluations of the POAMA2 forecast system at a more localised scale, that it exhibits moderate to high prediction skill in many locations around Australia. POAMA2 captures the main rainfall bearing processes at these two sites with forecasts being in the same tercile as observations between 57 to 74 percent of the time. These results are consistent with those found by Asseng *et al*. (2012) for four sites in the Western Australian wheat belt, where POAMA2 had improved skill over empirical forecasting systems. The skill level found at these sites approaches the levels reported by Crean *et al*. (2015), where farm level economic benefits for forecast use begin to accrue when prediction skill of soil moisture reaches 60-70%. This is similar to the findings of Asseng *et al*. (2012) where the level of skill available from POAMA2 started to accrue greater economic benefit to the farmer, through improved application of nitrogen fertiliser. Understanding how climate forecasts can be used to improve production and financial performance in a given agricultural system and location is complex. Broad options at these locations would include careful management of planting times, determining the area and crop variety to plant, controlling stocking rates, pre-empting health issues in livestock, managing water and fertiliser applications and optimising harvesting times.

Conclusion

POAMA2 was able to provide a hit rate of 57 to 73% rainfall forecasts at these sites. Long term averages of agricultural yields are reproduced with moderate to high accuracy, although there appears to be a tendency to both underestimate and overestimate extremes in production at these sites. As a next step the utility of using forecasts to modify one or more of these management options needs to be tested at these sites. Climate prediction skill may also be improved at the farm level by using a more sophisticated downscaling system. Work of this nature leads to the development of farm specific decision support that optimises the use of forecasting for each location and production system.

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Characterization of maize growing environments in eastern and southern Africa using the APSIM model

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Abstract
Maize grown in eastern and southern Africa experiences random occurrences of drought. This uncertainty creates difficulty in developing superior varieties and their agronomy. Characterisation of drought types and their frequencies could help in better defining selection environments for improving resistance to drought. We used the well tested APSIM maize model to characterise major drought stress patterns and their frequencies across six countries of the region including Ethiopia, Kenya, Tanzania, Malawi, Mozambique and Zimbabwe. The database thus generated covered 35 sites, 17 to 86 years of daily climate records, 3 varieties and 3 planting densities from a total of 11,174 simulations. The analysis identified four major drought environment types including those characterised by low-stress which occurred in 42% of the years, mid-season drought occurring in 15% of the years, late-terminal stress which occurred in 22% of the years and early-terminal drought occurring in 21% of the years. These frequencies varied in relation to sites, genotypes and management. The simulations showed that early terminal stress could result in a yield reduction of 70% compared with low-stress environmental types. The study presents the importance of environmental characterization in contributing to maize improvement in eastern and southern Africa.

Key words
Drought stress, environmental types, GxE interactions and Zea mays L.

Introduction

In eastern and southern Africa maize (*Zea mays* L.) is predominantly grown in small-holder farming systems under rain-fed conditions with limited inputs. This generates high genotype x environment interactions which complicates the efforts to develop superior varieties and their agronomy. Breeders have been classifying environments based on results from multi-environment trials conducted over locations and seasons. Due to time and cost constraints, mapping of the entire maize growing region cannot be performed using this approach. Better understanding of temporal dynamics of water stress patterns experienced by the crop and the frequency with which each pattern occurs in the maize growing areas can be achieved using crop models (Chapman et al., 2003). It can also help to estimate the phenotypic performance of traits in specific managements and environments that are difficult through use of multi-environment trials (Hammer et al., 2013). Studies on several field crops have used this approach in different parts of the world to characterise the water-deficit patterns experienced by a crop (Chauhan et al., 2013; Chenu et al., 2013; Hammer et al., 2014; Harrison et al., 2013). Characterisation of maize growing environments in eastern and southern Africa using long-term climate data based on crop simulations has, however, not been attempted. Therefore, this study was initiated to identify types and frequency of stresses, and identify iso-environments based on the similarity of stress patterns.

Materials and methods

The study was carried out for six eastern and southern African countries including Ethiopia, Kenya, Tanzania, Malawi, Mozambique and Zimbabwe (Figure 1). Thirty five probe sites from these countries were selected to represent major maize production areas in these countries. The efficacy of APSIM maize model was tested using yield data recorded from 16 eastern and southern Africa maize testing sites for five hybrids ($r^2 = 0.84$) and the result can be obtained upon request from the authors. The specific planting window for each site and relevant soil types were determined based on expert knowledge and from

secondary information. The planting window for southern Africa countries including, Malawi, Mozambique and Zimbabwe varied between November 1 and January 15. In eastern African countries of Kenya and Tanzania, which are characterized by bimodal rainfall, the planting window for the long rainy season varies between February 20 and April 30 whereas for the short rainy season varies between 1 and 30 October. APSIM parameterized maize varieties of different maturity groups including early, medium and late with three different planting densities (4, 5 and 6 plants/m2) were used to identify the potential stress levels in the region. To avoid the confounding effects of nitrogen with water stress, nitrogen fertilizer was considered as non-limiting and set to the maximum, 300 kg/ha. Daily weather data including maximum and minimum temperature, rainfall and solar radiation were accessed from different sources. The period for which these data were available varied from 17 years to 86 years. Plant available soil water at planting was set to 30 mm within the planting window to initiate germination. The temporal pattern of daily crop water stress (water supply/demand (SDR)) for each simulation was centred at anthesis and averaged at every 100oCd from 400 ^{o}Cd before anthesis and 700 ºCd after anthesis. SDRs were clustered using the R program (R Core Team (2014)), and major drought patterns determined. Further, sites were clustered into four yield clusters, cluster 1 to 4, based on simulated yield.

Figure 1. Map of the study countries and sites in eastern and southern Africa.

Results

Drought patterns and their yield distribution in the region

Maize growing sites in eastern and southern Africa were clustered into four distinct major maize environmental types (Figure 2a). The sites that were dominated by low-stress environmental types (LS) comprising situations where plants were not limited by drought, with SDR being close to unity. Mid-season stress environmental types (MS) were characterized by stress that started early at the vegetative stage, exposed the crop to drought at anthesis and relieved by rainfall events during the late grain filling stage. The late terminal (LT) and early terminal (ET) environmental types differed on severity and time of the onset of drought. The late terminal drought environmental types (LT) commenced after flowering and the crop experienced drought late at the grain filling stage while early terminal drought environmental types (ET) started early at the vegetative stage, stressed the crop with increasing severity from anthesis to maturity. These drought types in the region were related with yield performance. The highest median yield (6.69 t/ha) was observed for LS while the lowest median yield (2.33 t/ha) was observed for ET (Figure 2b).

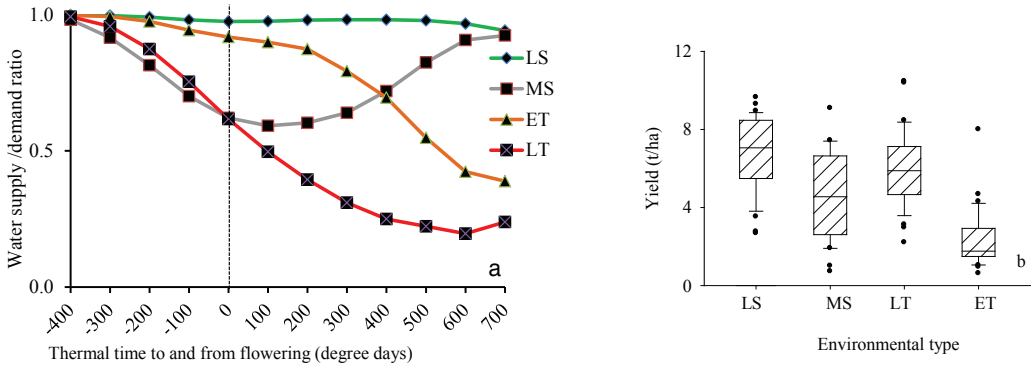

Figure 2. Water supply and demand ratio as a function of thermal time around flowering for the environmental types identified in maize growing sites in the region (a) and their yield distribution (b). Vertical bars and points outside the box plots indicate the standard errors and the outliers in each environmental type respectively.

Frequency of drought patterns in the region

The frequency of occurrence of LS, MS, LT and ET environmental types was 42, 15, 22 and 21% of the seasons, respectively (Figure 3a). The frequency of occurrence of these environmental types, however, was highly variable across sites and yield clusters (data not shown). The range of frequency of occurrence of different environmental types at each maize growing site was different. For instance, the frequency of MS, LT and ET ranged from 0 to 61, 4 to 37 and 0 to 77 respectively across different sites. ET was more frequent accounting for 43% of the seasons at sites in yield cluster 1 (Figure 3b). However, in sites of yield cluster 4 LS environmental types accounted for 68% of the seasons. The frequencies of occurrence of terminal drought environmental types increased from early maturity variety Katumani to late maturity variety H614 as the planting density increased from 4 to 6 plants/m^2 (Figure 3b). However, changes in stress frequency due to changes in maturity and density were higher for the sites in yield cluster 2 and 3.

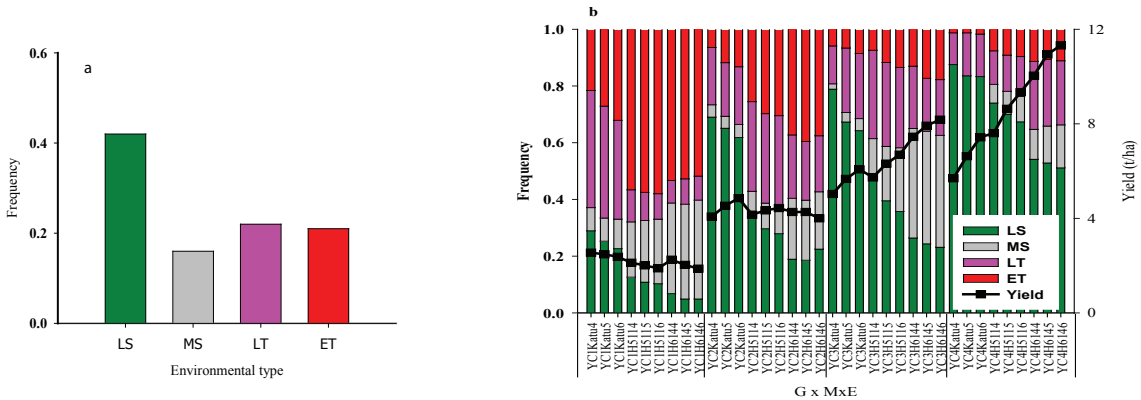

Figure 3. Frequency of occurrence of environmental types in the region (a) and for each combinations of variety x density x environment (GxMxE) in each yield cluster. The numbers 4 – 6 are the densities 4 to 6 and genotypes Katu, H511 and H614 are early maturity variety Katumani, medium maturity variety H511 and late maturity variety H614 respectively. YC1 to YC4 are yield cluster 1 to 4.

Discussion

Drought frequencies varied across sites, maturity and management in the region

Broad ranges of drought patterns occurring in the region were classified into four major environmental types (Figure 2a). The stress free environmental type (LS) was more frequent in the region (42 % of the seasons) (Figure 3a). This was higher than non-stress environmental type frequency reported for different crops in Australia (Chauhan et al., 2013; Chenu et al., 2013; Hammer et al., 2014) and closer to that reported for maize in Europe (Harrison et al., 2013). The frequency of environmental types varied in relation to maturity and planting density in the region. MS and ET environmental types were least frequent for early maturity variety while the late maturing type experienced frequent terminal stress particularly in environments with low growing season rainfall (Figure 3b). This is because earlier flowering mostly increases LS conditions and could be recommended to escape water stress in the absence of other limiting factors around flowering

(Chenu et al., 2013). Earliness *per se* will reduce yield potential (e.g., in yield cluster 3 and 4). This emphasizes the relative merits of different traits for various target population of environments (Harrison et al., 2013; Hammer et al., 2014).

Yield variability in the region

The range of yield difference in the region was very high, 1.3 to 9.7 t/ha. Across the region a close relationship between rainfall and maize yield was observed (Figure 3b). As expected, the highest grain yield was observed for the LS environmental types (Figure 2b). However, yield was significantly reduced for MS and ET environmental types. This was attributed to the stresses coinciding with flowering and grain filling stages of the crop. High yield reduction, 70 %, in our study for ET stress environmental types was consistent with the previous reports 55 - 75 % reduction in yield from drought stress created by withholding irrigation before flowering to maturity (Cairns et al., 2013). Smaller (8 to 10 %) yield reduction, observed for LT suggested that the crop experienced the stress at the late grain filling stage, after good synchronization and seed set were secured.

Conclusion

The eastern and southern Africa maize growing environments can be classified into four environmental types based on timing, intensity and frequency of drought, i.e. water non-limiting, mid-season stress, late terminal and early terminal stresses environmental types. When other abiotic stresses are alleviated, targeting breeding objectives based on environmental types could provide a better framework for breeding and agronomy research. For instance, it could enhance germplasm deployment over similar environmental types across the region and optimize resources that are scarce and usually constraining breeding and agronomic research in eastern and southern African countries.

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Assessing long-term (2004 to 2014) effects of rotation and tillage on grain yield and soil C and N of a medium rainfall temperate cropping system

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Abstract
Growers and advisers face an array of options when considering what rotation and tillage management practices to use. The SCRIME (**S**ustainable **C**ropping **R**otations **I**n **M**editerranean **E**nvironments) experiment was established in 1998 on a Vertosol soil in a 425 mm rainfall environment in the Victorian Wimmera to assess how rotation and tillage practice influence long-term crop productivity and the underpinning soil resource. Since 2004, seasonal conditions have ranged from several years of drought and crop failure to a 1 in 200 year rainfall event. Results indicated that fallowing consistently produced higher wheat yields than continuous cropping, whereas the use of a green manure (vetch) did not. Long-term tillage (zero vs conventional) practice had no significant effect on the grain yields of wheat. Inclusion of a green manure or a 3 year lucerne phase produced significantly greater soil C and N whereas fallowing resulted in lower N and C compared to other treatments. Increased soil total N and C did not necessarily result in higher plant available N levels at sowing. Results from SCRIME demonstrated the value of long-term trials to understand the complex inter-relationships between management, crop productivity and the soil resource.

Key words
Vertosol, soil nitrogen, soil carbon, fallowing, green manure

Introduction
During the 1990's there was a fundamental change in cropping systems in the medium rainfall zone of south-eastern Australia towards continuous cropping (fewer pastures, resulting from decreased wool prices), reduced fallowing and the development of non-cereal cropping options such as canola and high value pulses. There has also been a progressive shift away from mechanical cultivation to conservation cropping practices.

As well providing a major economic benefit as a commodity, rotations with non-cereal crops such as canola and pulses provide important benefits to the cereal phase via improved nitrogen nutrition and weed and disease breaks (Kirkegaard et al., 2008). The complexity of different rotation options makes understanding the impact of different rotation options on subsequent crops difficult to assess. Recently a GRDC funded 'Break – Crop' Initiative has assessed short-term impacts (< 5 years) of rotations on wheat. However changes in agronomic management practices, including rotations and tillage practice, can produce small changes e.g. soil nitrogen (N) and carbon (C), that are difficult to detect in the short-term but which can significantly impact on the productivity and sustainability of these systems in the longer-term.

This paper reports some key findings from the long-term experiment SCRIME (**S**ustainable **C**ropping **R**otations **I**n **M**editerranean **E**nvironments). SCRIME aims to assess how different rotations (pasture legumes, pulses and oilseeds) and tillage practices affect the productivity and sustainability of the underpinning soil resource. In this paper we focus specifically on changes in grain yields of wheat since 2004 and soil N and C levels in selected treatments.

Methods
Treatments were designed to represent the very diverse rotational options available to grain growers in medium rainfall environments of south-eastern Australia. The experiment originally comprised 10 rotations x 3 or 6 phases x 3 replicates (total of 108 plots) in plots 14 m wide by 36 m long, but since 1998 some changes have been made in response to industry interest and prudent agronomic management. In 2004, Treatment 2 (continuous wheat – 2 x rate of sowing N and P fertiliser) was modified to canola-wheat-pulse (zero tillage), allowing direct comparison with reduced and conventional tillage viz. T6 and T7, respectively.

Phase 2 (wheat) is used as a 'bioassay' of the rotation effect within the trial. This design combines benefits of both 'rotation' and a 'break crop' experiments (Angus et al 2015). SCRIME is located on an alkaline grey Vertosol soil, which had a long history of prior cropping.

The Treatments were:
1. continuous wheat (WWW)
2. canola - wheat – pulse: Zero Tillage (CWP ZT)
3. pulse - wheat - barley (PWB)
4. green manure/fallow - wheat – barley (GmWB)
5. pulse - cereal - pulse (*discontinued in 2008*)
6. canola - wheat – pulse: Reduced till / stubble burnt (CWP RT))
7. canola – wheat - pulse : Conventional tillage/ stubble incorporated (CWP CT)
8. lucerne - lucerne – lucerne/fallow - canola - wheat - pulse (LLL CWP)
9. green manure - canola - pulse – medic pasture - wheat - barley (GmCPMWB)
10. fallow – wheat – pulse (FWP)

Except for T7 and T2, treatments are managed as reduced tillage where stubble is burnt in April (depending on stubble load). The pulse phase was chickpeas (1998), field peas (1999-2012) and lentils (2013 to date). Pastures and the vetch green manure are slashed and the residue retained on the plots. A basal application of MAP and urea (19 kg P/ha and 27 kg N/ha) was applied with the seed at sowing; in 2011 this basal N rate was reduced to 8.7 kg N/ha. A subplot comprising application of additional N (23 kg N/ha urea topdressed at mid tillering) has been incorporated into the Phase 2 wheat plots to permit an assessment of the N responsiveness of the treatment since 2007. Grain yield was measured using a small plot header. Grain protein was measured by NIR: Weather data are collected from the automatic BoM station located approximately 500 M away. Soil total N and C content (0-10 cm) was measured on samples collected in February 2014 from selected plots and total C and N were determined by combustion using a Leco™ analyser (Rayment and Lyons 2011). The topsoil (0-10 cm) is sampled in April each year prior to sowing and nitrate determined following extraction (1:10) in 2 M KCl followed by colorimetric analysis on a Lachat™ Auto Ion analyser.

Results

Both growing season rainfall (April-November, GSR) and annual rainfall between 2004 and 2014 were 16 and 19% respectively below the long-term average, although annual rainfall in 3 of the 11 years (2009 to 2011) was well above average (Table 1).

Average wheat grain yields were generally low, including 2 complete crop failures and 3 very poor crops (2004, 2006 – 2008, 2014) over the 11 growing seasons reported (2004 and 2014) (Figure 1), reflecting dry seasonal conditions. Except in 2006 and 2009, wheat following a fallow out yielded all other treatments in both low and high rainfall seasons. Initially grain yields in the WWW treatment were similar to the other non-fallowed plots, with the exception of 2005, until 2011. Following two wet years (2010 – 2011) wheat yields progressively declined relative to other rotations. Since 2008, when N fertilised subplots were included in the experiment, there had been a nil or a negative effect of additional N on grain yields of wheat in 5 out of the 7 years, with an average positive yield stimulus in 2011. In 2014, adding extra N produced a significant grain yield response in WWW and CWP ZT treatments, a significant decrease in the GM WB and no effect in other treatments (data not presented).

Table 1: Growing season rainfall (GSR) and annual rainfall (mm) since 2004

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	ave (1998-2014)	mean (1895-2014)
GSR (mm)	250	291	161	250	193	398	367	256	254	300	215	267	316
Annual (mm)	314	407	197	372	322	446	624	555	315	335	266	378	414

From 1998 to 2006, there were no significant (P <0.05) effects of rotation or tillage method on C or N concentration (data not presented). By February 2014 however, significant treatment differences were apparent , with the highest stocks of soil TOC (pooled across all phases) recorded in the GM WB treatment, followed by CWP CT and LLLCWP treatments with the lowest SOC recorded in the FWP treatment (Table 3). There were similar patterns in soil total N, with highest concentrations in the LLLCWP and GM WB treatments, followed by CWP CT with significantly less N (P <0.05) in the FWP treatment. Soil C:N ratio was lowest in LLLCWP rotation and highest in the CWP ZT and FWP treatments.

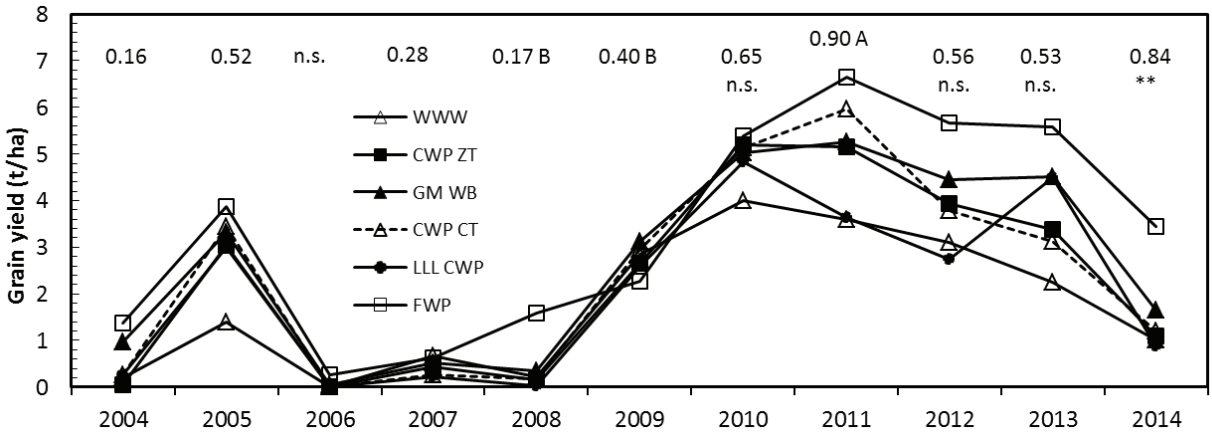

Figure 1: Grain yield of wheat phase from 2004 to 2014. Numbers represent lsd (5%). Letters after number represent response to additional N application: n.s. = not significant; A = positive response ; B = negative response; ** represents significant (P < 0.05) interaction between treatment and N fertiliser.

Table 3: Influence of rotation and tillage practice on soil organic C and total N (t/ha) and C:N ratio in the 0-10 cm layer in SCRIME (February 2014). Treatments marked by the same letter are not significantly different (Fishers protected l.s.d., 5%).

Treatment	SOC (t/ha)	STN (t/ha)	CN RATIO
1. WWW	7.48 abc	0.69 b	10.9 bc
2. CWP ZT	7.79 bcd	0.69 b	11.3 c
4. GMWB	8.54 e	0.78 cd	10.9 bc
7. CWP CT	8.10 cde	0.76 c	10.6 b
8. LLL CWP	8.21 de	0.82 d	10.0 a
10. FWP	6.98 a	0.62 a	11.3 c

Profile soil nitrate measured prior to sowing each year varied markedly between treatment and season (Table 4). Soil nitrate was generally highest when the proceeding fallow period (December – March, inclusive) experienced (unseasonal) high rainfall e.g. 2010 and 2011. Profile soil nitrate was consistently lowest in the WWW and highest in the FWP treatments, but in treatments involving a legume phase (GM WB and LLL CWP), the relative amounts varied inconsistently between years. For example, the two treatments with green manure (T4 and T9) produced the highest and second highest amounts of profile nitrate across all treatments in 2010 and 2011, 2012 and 2014, whereas there was no difference from the other cropped treatments in 2009 and 2013. Long-term tillage practice did not significantly alter soil nitrate prior to sowing wheat.
In the LLL CWP and GM WB treatments, the greater amounts of nitrate present at sowing also generally corresponded to a more even distribution of this nitrate throughout the profile, whereas this nitrate was concentrated in the topsoil in other treatments (data not presented).

Discussion

Grain yields in the Wimmera depend heavily on soil water availability, N supply and disease. In a study period characterised by long-term below average annual and GSR rainfall, as well as Decile 10 years (2010 and 2011), a preceding chemical fallow consistently produced the highest yields in the following wheat crop. A Vetch Green Manure phase significantly increased soil total N (STN) and nitrate supply, and to a lesser extent soil water (data not presented), also increased the grain yield of the following wheat phase, but not to the same extent as the fallow. In contrast, despite high underlying STN levels (Table 3), the amount of soil nitrate prior to sowing wheat in the 3 year Lucerne pasture rotation were generally no different from other continuous cropping

treatments. Consequently relatively poor wheat yields were recorded for wheat crops following Lucerne, the exception being in 2013, which also corresponded with relatively high soil nitrate levels at sowing.

Table 4: Profile (0-120 cm) soil nitrate (kg/ha) prior to sowing of the wheat phase in selected treatments between 2009 and 2014. n.d. not determined.* ANOVA-F = 0.064 Rainfall from December of previous season to March. Soil sampling undertaken in April each year.**

			Year			
Treatment	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
1. WWW	44	59.3	27.3	44.8	15.1	21.2
2. CWP ZT	62.9	124.2	84.8	54.6	30.8	31.1
4. GM WB	67.7	205.9	127.3	91.2	33.6	80.4
6. CWP RT	53.6	104.5	67.9	53.8	17.6	76.6
7. CWP CT	49.8	n.d.	n.d.	n.d.	35.4	43.4
8. LLL CWP	68.4	167.4	47.7	72.5	90.1	78.7
10. FWP	129.1	131.3	181.7	128.6	83.7	160.6
l.s.d. (P<0.05)	30.1	36.4	45.7	26	29.7	40.1*
*Rain (mm)***	87	164	375	97	42	45

There was no clear relationship between STN (or TOC) and N mineralisation measured during the summer fallow. For example, STN was highest in the LLL CWP rotation and lowest in the FWP, but often the pre-sowing nitrate levels for these two treatments were reversed. Soil water availability appears to affect the variation in annual N mineralisation rates (Table 4), especially as the greater potential for N mineralisation measured in the LLL CWP rotation (K Dunsford unpub. data) also corresponds with the reduced plant available water levels that generally occur after terminating the lucerne phase (McCullum et al 2001). Although nitrate accumulation may remain high in the short term in fallow plots, declining soil TOC and TN data (Table 3) suggest that this is not sustainable in the longer-term.

Tillage practice did not affect wheat grain yields even after 10 years of treatment and a range of seasonal rainfall conditions. Zero tillage/stubble retention can benefit grain yields via improving soil water supply resulting from increased infiltration (e.g. Bissett and O'Leary 1996) although it can also reduce establishment on hard setting soils (Chan et al 1987). However in the present study, which was conducted on a physically well- structured Vertosol soil and in an environment characterised by low intensity winter dominant rainfall, zero tillage appears to provide no immediate production or soil benefits to grain production, at least for wheat.

The continuation of SCRIME provides the opportunity to investigate other rotation and tillage related factors impacting on the long-term sustainability and profitability of grain production in Wimmera farming systems including weed dynamics and the validation of soil health indices against long-term crop productivity.

Acknowledgements
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Biodiesel production in New Zealand – opportunities and considerations

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Abstract
Biodiesel is frequently promoted as an alternative 'green' energy source that could lead to fuel security for the transport and farming industries. However, the growing of such crops has been criticised for taking valuable arable land out of food production and thus, in fact, reducing food security. To mitigate these effects, it has been proposed that marginal soils be used for biodiesel crop production.
In this New Zealand study a diverse range of oilseed species were evaluated for biodiesel production on both high quality arable soils and on marginal land. On the marginal soils grain yield and oil production were low and variable, with Camelina (*Camelina sativa*) and canola (*Brassica napus*) out-yielding all other species tested. On the higher quality arable soils much higher yields were achieved, with canola out performing all other species tested.

In New Zealand, dryland marginal soils are primarily used for intensive sheep meat production or where irrigation is available, may have been converted to dairying; therefore the notion that these soils are not used for food production is simplistic. Changing farming systems on these marginal soils to biodiesel production would lead to increased farm risk. Alternatively, producing biodiesel from high producing canola crops on quality arable soils would likely provide benefits such as improved crop rotations and regional fuel security.

Key words
Biofuel, fuel security, marginal soils, oilseed crops.

Introduction
In 2006 the New Zealand government passed legislation that required oil companies to meet a biofuels sales obligation which required 3.4% of total petrol and diesel sold be biofuel by 2012. To support this the Biodiesel Grants Scheme was established which allowed for grants of up to 42.5 cents per litre to eligible biodiesel producers. The purpose was two-fold: biodiesel would decrease greenhouse gas emission by 19-54% (Campbell and McCurdy 2008; Tate and Purchas 2008) and increase New Zealand's fuel security as oil production occurs in volatile regions of the world. Diesel use in New Zealand is 111 PJ (Rosevear 2008) which converts approximately to 3 billion litres. Agriculture, industry, transport and the retail sector accounts for 10.6, 12.2, 24.8 and 40% of diesel use respectively (Rosevear 2008). The level of biofuel production needed for the governments mandated percentage is approximately 100 million litres. It is estimated that recycled cooking oil could produce 3 to 5 million litres whilst tallow could produce 150 million litres although there are higher value markets available for tallow (Hale et al. 2006). However, the legislation on mandated levels and the subsidy of biofuels has since been repealed and lower oil prices have reduced fuel security concerns.

In temperate environments, canola (*Brassica napus* L.) is the main crop source for biodiesel. Increasing the area of crops for biofuel production has been criticised for impacting on food security because land that was once producing food has been switched to fuel production resulting in increased food prices (Timilsina and Shrestha 2011). There is therefore an interest in using marginal land for biodiesel crops to reduce the direct competition. The programme described in this paper aimed to identify for NZ new oil bearing plants with the potential for use as biodiesel feedstock. The crops should be produced sustainably on marginal land, should not be major arable food crops and should not require high fossil-fuel based inputs. Approximately, 1.4 Mha of land in New Zealand is classified as highly suitable for arable farming (LUC 1 and 2), about 2.4 Mha is considered as arable but with moderate limitations, whilst 2.8 Mha arable land has severe limitations (Our Environment 2014). Interestingly, harvest data of all the main seed crops reveals approximately 200, 000 ha sown each year (Agricultural Census tables 2012). The area is increased by a further 400, 000 ha

when annual forage brassicas, cereal forage crops and maize silage are included (Agricultural Census tables 2012). In comparison, exotic grassland covers 10.5 Mha including flat cultivatable land and hill country (Our Environment 2014). Marginal land can include stony soils with low water holding capacity, low fertility soils and pumice soils. Other oilseed species that were included in the programme were, camelina (Camelina sativa L. (CS)), brown mustard (Brassica juncea L. (BM)), meadowfoam (Limnanthes alba Hartw. (MF)) and pennycress (Thlaspi arvense L. (PC)).

Method

Field experiments 2009 and 2010

In 2009 and 2010 five oilseed species at three different sites were sown in autumn and spring. Only autumn sown treatments are presented here. Further details are described by McKenzie *et al*. (2011). Locations included Ashley Dene - 7km from Lincoln, with a very stony silt loam soil. Oxford, in the foothills of the southern Alps, a very wet and low phosphorus site; and Taupo in the North Island with a light pumice soil. Nitrogen was applied at each site at 50 and 150 kg/ha although only the high nitrogen treatment is reported here. In 2009 sowing occurred at Ashley Dene on 5 May, at Taupo on 11 June and sowing was delayed at Oxford due to a wet autumn and occurred on 27 August. Autumn sowings at Ashley Dene of canola and BM were re-sown on 25 June due to bird damage. In 2010 sowing dates at Ashley Dene was 18 March although autumn sown CS was abandoned due to plant death. Only spring sowing was conducted at Oxford and Taupo in 2010 and is not included in this data. Biomass and development was measured throughout the season but only grain yield is reported here.

Field experiment 2010

An experiment with three oilseed species over four sowing dates was conducted on a deep silt loam soil at Lincoln University in 2010. Only the March sowing date is reported here. Further details are described by (Fasi et al. 2012). The experiment was irrigated at 50% plant available water to prevent water stress. Biomass and development was measured throughout the season but only grain yield is reported here.

Commercial field sites 2012

Field sites were established throughout the main cropping zones in New Zealand with the primary purpose of providing validation data for APSIM (Agricultural Production Systems sIMulator) modelling, but this work is not reported here. Location of the sites included; Hilderthorpe, Waimate, Makikihi, Fairlie (x2), Cave, Temuka, Kirwee, Burnham, Fielding (x2) and Sanson. All locations were on cropping farms with quality arable soils and/or irrigation available. All agronomic management was conducted by the co-operating farmer with four replications of measurements taken from a fixed area within the crops. Biomass and development were measured throughout the season but only grain yield is reported here.

Results

Seed yield was highly variable across sites and seasons (Table 1). When sown on a low water holding capacity soil at Ashley Dene in 2009, May sown MF produced 1551 kg/ha and was the most productive species. The canola and BM was re-sown which resulted in reduced yields less than 900 kg/ha. Seed yields at Oxford and Taupo were greater than for Ashley Dene primarily because soil water was less limiting. At Oxford, canola achieved the highest seed yield. Sowing in June at Taupo resulted in canola and BM yielding more than CS while Meadowfoam performed very poorly. Pennycress failed to establish properly at most sites due to disease and weeds. It was identified that canola and BM were the most promising species for further development on marginal soil. Camelina was also included as it had performed well in spring sowings (data not shown).

Table 1. Seed yield of five species at four sites in New Zealand

Year	2009			2010	
Site	Ashley Dene	Oxford	Taupo	Ashley Dene	Lincoln
Sow date	May[a]	August	June	March	March
Canola	823	2448	2304	1490	2939
BM	201	1577	2078	307	773
CS	601	1105	1397	-	664
MF	1551	401	476	ns	ns
PC	-	-	-	ns	ns
Signif	< 0.01	< 0.01	< 0.001	NS	< 0.01
LSD	631	336	787		471

[a] OSR and BM were resown on 25 June. NS – not significant. ns – not sown.

In 2010 at Ashley Dene, the autumn sown CS died during winter while canola had increased yield compared to the previous season but was variable. Canola produced the greatest yield for March sowing at Lincoln University in 2010. Not only were seed yields different, but oil yield percentage was different between crops; canola averaged 42% compared with BM and CS at 30 and 33% respectively. Therefore canola not only out yielded the other species but also produced a greater concentration of oil.

Seed yield from commercial canola crops across New Zealand were compared and ranged from 3177 to 5936 kg/ha, at an average of 4500 kg/ha. Crops achieved high harvest indices with an average of 35% and an average thousand seed weight of 4.5g.

Estimating how much land would be required to meet the biodiesel requirements was extrapolated from oilseed yields (Figure 1). If the total mandated requirement was to be met through oilseed production on high quality arable land this would require approximately 60,000 ha with an average yield of 4500 kg/ha. Reducing the biodiesel requirement (but still with a seed yield of 4500 kg/ha) to 50 and 25 million litres would reduce the required land area to 30,000 and 15,000 ha respectively. Moving crops to marginal soils in which maximum yield was 1500 kg/ha would require three times this land area.

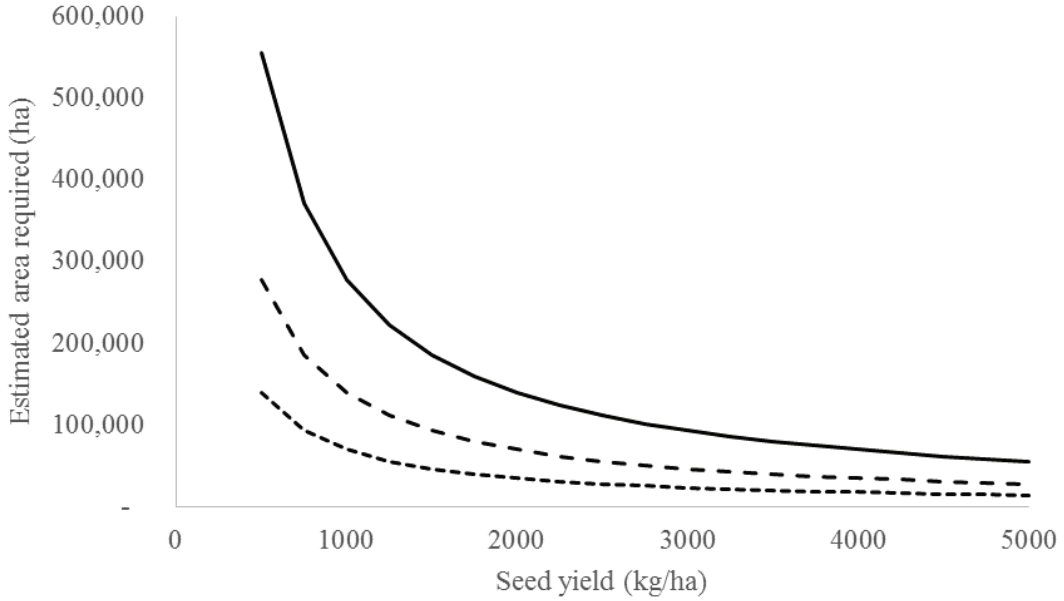

Figure 1. Estimated area required for three levels of biodiesel production (100 million litres solid line, 50 million litres dashed line and 25 million litres dotted line) for a range of seed yields.

Discussion

Under a range of soil conditions canola was as productive or more productive than the other species considered. These results should not be surprising because of the large investment into breeding improved cultivars of canola over many decades. In fact, there is likely to be a number of canola cultivars bred for short-season conditions that were not tested here due to their lack of availability in New Zealand. *Camelina sativa* could be a useful species for New Zealand environments but it has not received the same concerted breeding effort. What should be noted is the yield potential differences between marginal soils and better arable soils. For soils with low water holding capacity seed yield appeared to be limited to 1500 kg/ha and to be highly variable. Canola sown in 2010 on better soils achieved 2900 kg/ha whereas farmers across 12 sites achieved an average of 4500 kg/ha with a maximum yield of 5936 kg/ha. Therefore it is questionable whether oilseed crops for biodiesel production be sown on marginal land. If marginal soils could average 1500 kg/ha, the area required to reach the New Zealand's governments previously mandated biodiesel quota would be 185,000 ha. Alternatively, if the canola was grown on high quality arable land with an average yield of 4500 kg/ha then 60,000 ha would be required. However, it should be noted that currently only 200,000 ha per annum is currently used for growing seed crops. Creating a biodiesel industry derived from oilseed crops would require a significant change in land use right across New Zealand. The land area required to reach the previous government's quota is very large, especially if crops from marginal soils

were to be included, and the biodiesel industry would have to compete with other industries such as dairy, processing crops and high value seed crops for land and resources. It is unlikely that grain for fuel could compete with these high value industries. If canola was used in the rotation on high quality soils every 5-10 years this would result in 20-40,000 ha being sown each year. This area of production would not satisfy a national demand for fuel but could supply a regional based industry.

Furthermore, the consideration to use marginal land instead of high quality arable land was due to concerns about encroaching on land that is required for food production. In New Zealand, marginal land is used for food production, primarily for sheep meat production. If the land has irrigation it could also be used for dairying. With regard to global food security, it is the increase in the animal protein requirements of the rising middle classes of developing countries that is likely to put the greatest pressure on production and also on ecological systems. Using marginal soil for cropping would directly impact on the production of grass-fed animal protein which tends to have a low environmental impact. Changing land use on marginal soils from pasture to cropping land is likely to increase risks to farmers without any improvements in financial returns. Grazing of pastures in autumn and spring is highly reliable compared to the growing of an annual grain crop, because such crops must reach full maturity before harvest, leaving them vulnerable to the weather. As shown in the Results section, there can be large variations in seed yield within and between seasons.

It is unlikely that the production of biodiesel will become a national industry due to the land requirement and competing industries. However, that does not mean that a regionally-based biofuels industry could not be successful. Arable farmers are able to produce high yielding canola crops and would require very small areas of land to supply their own needs. An arable farm may use 100 litres of diesel per hectare. Therefore, to be self-sufficient, a canola crop with a yield of 4500 kg/ha would only require approximately 6 ha for every 100 ha of crops sown. This would not greatly change the diesel use profile in New Zealand, but it could boost regional communities, secure their fuel supply and stabilise the price of fuel.

Conclusion

On marginal land, canola is as productive and often more productive than other alternative oilseed crops, but yields on marginal land are low and variable compared to those from high quality arable land. Producing biodiesel on marginal soils affects food production because in New Zealand these soils are used for the production of sheep meat and dairy products. To produce sufficient diesel to reach original government mandated quotas would require large areas of land compared to the areas that are currently used for cultivation. Producing biodiesel from canola on high quality arable soils in support of regional industries could reduce farmers' reliance on world oil production and increase regional economic activity.

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A review of annual intercrops in rainfed farming systems of southern Australia.

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Abstract
We undertook a literature review of intercropping in the southern Australia wheatbelt. Literature included published peer reviewed journal articles and conferences; and grey literature sources (technical reports, thesis and un-refereed conferences). The review found very little published research on intercropping in this zone. Four groups of intercropping research in Australia were identified: 1. 'Peaola' (Canola-field pea intercrops); 2. Cereal-grain legume intercrops; 3. A single experiment where faba bean and field pea were intercropped; 4. Mixtures of cereal varieties. The land equivalent ratio (LER) was used to evaluate the potential productivity benefits of intercropping. An LER greater than 1.0 indicates that there is a productivity benefit from sowing the intercrop. Peaola intercrops had the greatest productivity increase with 70% having a LER greater than 1.5 (n=34). The cereal-legume intercrops (mostly lupins and chickpea) had 64% with LERs greater than 1.0 (n=22), but there were no published Australian example of wheat-field pea intercropping. None of the five Australian examples of cereal variety mixtures increased grain yield, which is at odds with published international research. This review highlights the potential for yield increases with intercropping in Australia (particularly peaola). Other possible residual benefits (increased N supply, reductions in weed and disease pressure) to subsequent crops should be considered.

Keywords farming systems, intercrop, mixtures

Introduction
Intercropping, the practice of planting two or more crop species simultaneously in a field. There can be substantial productivity and efficiency benefits from the practice (Lithourgidis et al. 2011). However, intercropping requires increased amounts of management and labour to deal with the extra complexity of the system. Intercropping is widely practiced in subsistence and organic. Mostly, these systems have access to sufficient labour to manage the extra complexity. In contrast, intercropping has not been widely practiced in large scale mechanized agricultural systems, such as in Australia, due to a scarce and expensive labour resource. Nevertheless there is a renewed interest in examining these systems in Europe, North America, China and South America due to potential increases in resource use efficiency and environmental benefits (Lithourgidis et al. 2011). For a number of reasons it is timely to re-evaluate the potential for annual intercrops in Australian grain cropping particularly in the temperate zones. There is evidence that intercrops can use soil water more efficiently than sole crops (Morris and Garrity 1993). Herbicide tolerant crops may also enable some innovative weed management strategies. Annual intercrops are a method to increase diversity of species in cropping systems that are now dominated by a few major crops. In this paper we report the results of a literature review of intercropping (including variety mixtures of a single species) in the rainfed farming systems of Southern Australia.

Scope of review
Peer reviewed (journal and conference) and grey literature (technical reports, theses and un-refereed conferences) were reviewed. The review was restricted to annual intercrops in rainfed farming systems of Southern Australia (with winter dominant rainfall patterns) and did not include mixtures with perennial species or summer crops. Mixtures of multiple varieties of a single species were included.

Productivity benefits were quantified by the land equivalent ratio (LER; Equation 1) (Mead and Willey 1980).

$$LER = \frac{ICY_a}{SCY_a} + \frac{ICY_b}{SCY_b} \qquad \text{(Equation 1)}$$

Where ICY_a = the yield of crop *a* as a component of an intercrop, SCY_a= the yield of crop *a* as a sole crop, ICY_b = the yield of crop *b* as a component of an intercrop and SCY_b= the yield of crop *b* as a sole crop . An LER greater than 1 indicates a productivity advantage of the intercrop.

In each of the cereal variety mixture experiments the grain was not separated into its component varieties.

Therefore it was impossible to examine the LER instead we reported relative total grain yield.

Results and discussion

There were only a small number of peer-reviewed journal articles on 'classical' intercropping experiments in Australia, i.e. two different crop species sown and harvested in the same season (Gardner and Boundy 1983, Jahansooz et al. 2007). There was more data available in theses, conference proceedings and online sources (Walton 1980, Turay 1996, Soetedjo et al. 1998a, Soetedjo et al. 1998b, Anon 1999, Soetedjo et al. 1999, Barraclough and Martin 2001, Soetedjo et al. 2003, Jahansooz and Coventry 2004, Bennet 2009, Sharma et al. 2011). Furthermore, when cultivar mixtures of a single crop were included there was yet more available information (Davidson et al. 1990, Abbott et al. 2000, Paynter and Hills 2008, Sharma et al. 2011, O'Callaghan and Johnston 2012). There were four groups of intercropping experiments (Figure 1): 1. Six publications with fieldpea-canola intercrops ('Peaola'). 2. Three publications with wheat-legume intercrops; 3. A single publication with faba bean-fieldpea intercrops; and 4. cereal variety mixtures publications. The yield results of the interspecies mixtures are summarised in figure 1.

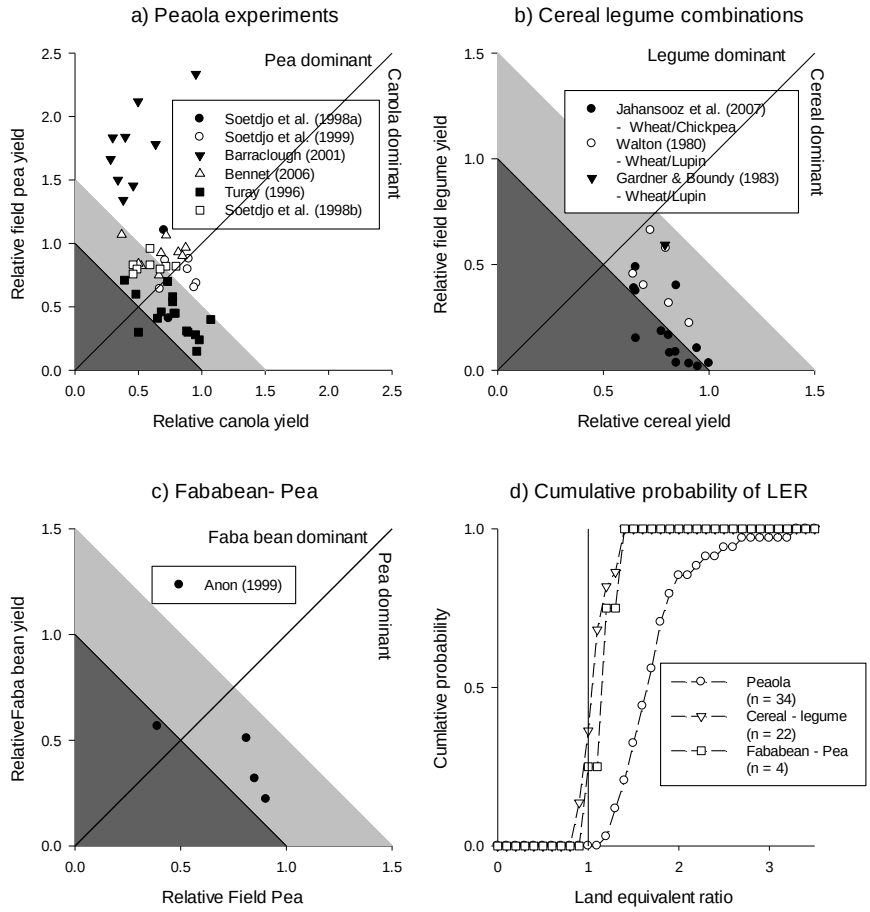

Figure 1. Summary of intercropping experiments in Southern Australia for (a) field pea-canola mixtures (b), wheat – legume mixtures (c) and faba bean – field pea mixtures (d); and the cumulative probabilities of LER across experiments (d). Each data point is a separate treatment. The dark grey area indicates the LER< 1.0; the light grey area indicates the 1.0< LER < 1.5; and the white area indicates the LER >1.5. The solid line in a, b and c is *y=x* for comparison of the competitiveness of each component crop.

There were 34 intercropping treatment combinations of peaola principally from WA. Peaola intercrops had high LER's (Figure 1a) with the LER exceeding 1.0 in all but one case and 1.5 in nearly 70% of cases (Figure 3d). The high field pea yields relative to their sole crops (> 1.5) found by Barraclough and Martin (2001) indicated that canola facilitated field pea yield possibly due to increased harvestability. With the exception of Barraclough and Martin (2001) the relative pea and canola yields were similar indicating that they had similar competitiveness. There is a potential for increased use of peaola intercrops in Australia. Identifying the basis of the yield benefit and the situations where peaola intercrops can contribute to farm profitability are critical issues. Furthermore, despite clear productivity benefits there has not been widespread uptake of peaola crops. The factors limiting this uptake also need to be identified.

There were 22 intercropping combinations across the three wheat-legume intercropping publications from Victoria, SA and WA (Figure 1b). Lupins (Walton 1980, Gardner and Boundy 1983) and chickpeas (Jahansooz et al. 2007) were the two legumes used. The LER exceeded 1.0 in 64% of cases (Figure 1d). Most of the cases where LER was less than 1 were in the experiments of Jahansooz et al. (2007). In all cases, the relative cereal yields exceeded the relative legume yields indicating that the cereal was more competitive than the legume. Surprisingly there were no Australian examples of wheat-field pea intercrops. There are many opportunities to further explore the role of annual wheat –legume intercrops in Australia.

In a single WA experiment (Anon 1999) field pea and faba bean were intercropped. The LER ranged from 0.95 to 1.30 (Figure 1c). The rationale was that it would result in more stable yields across seasons. However, it was impossible to test this with the results of only 1 season.

There were five publications examining cereal variety mixtures. None of the experiments found evidence of grain yield increases (Davidson et al. 1990, Abbott et al. 2000, Paynter and Hills 2008, Sharma et al. 2011, O'Callaghan and Johnston 2012). The median of the mixture yields relative to the expected average yields of the components of each mixture was 1.01 (Figure 2a). However a more appropriate comparison would be the mixture yield relative to the yield of the highest yielding variety. In this case the median relative yield was only 0.94. These demonstrate that there was little direct productivity benefit in growing mixtures of cereals. In contrast a global meta analysis of cereal variety mixtures found a -30 to +100% grain yield increase (Kiær et al. 2009). It is unclear why similar yield gains are not realised in Australia.

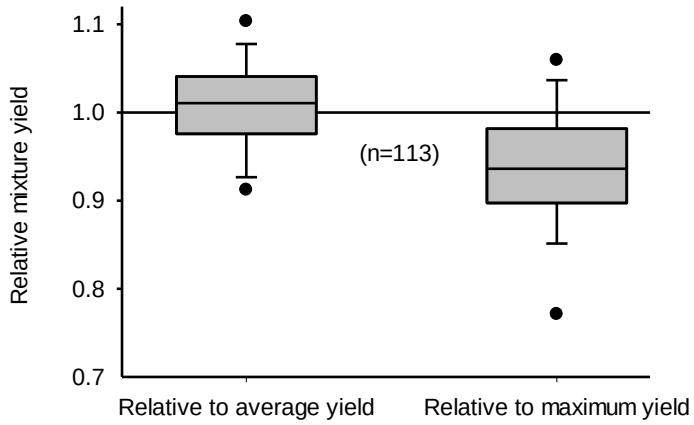

Figure 2. Box plots of relative yields of cereal crop variety mixtures compared with either average or maximum yields of the component varieties.

Even though there were no grain yield increases, the experiment of Davidson et al. (1990) showed that growing a mixture of short season spring and long season winter wheat varieties could provide early season grazing, from the spring wheat, with very little loss in the subsequent grain yield of the winter wheat. There is the potential to use variety mixtures of cereals to produce asynchronous crop reproductive development to manage the risks of frost and heat stress that can impact yield in many regions. This approach is likely to improve the stability of cereal yields rather than increase average yields.

The review has focussed on the immediate productivity benefits of crop mixtures as measured by the LER. This simple measure examines the efficiency with which a given land area is used to produce grain. However, there are a myriad of other benefits that need to be assessed in Australian systems. For example, intercrops may have more or less weeds than sole crops (Lithourgidis et al. 2011), they may decrease disease pressure (Boudreau 2013), they may contribute to yield stability rather than just average productivity, they may provide soil N benefits to subsequent crops (Hauggaard-Nielsen et al. 2009), may contribute to increase P uptake (Gardner and Boundy 1983) or more efficient complete and efficient use of soil water (Morris and Garrity 1993). All these aspects need to be examined in order to fully evaluate the use of annual intercrops in Australian cropping systems.

Conclusions

There is scant research on intercropping in the rainfed farming systems of Southern Australia. The limited research suggests that there are potential productivity benefits that could be obtained. Furthermore, there are some further potential rotational benefits that need to be researched. Despite these potential benefits there

has not been widespread uptake of intercropping in southern Australia. This may be due to the perceived logistical challenges to managing these systems. The factors limiting the uptake and use of intercropping also need to be identified.

Acknowledgements
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Industrial hemp in New Zealand – potential for cash cropping for a better environment in the Taranaki region

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Abstract
'Landfarming' in the Taranaki district in New Zealand (NZ) is the process of soil bio-remediation after spreading hydrocarbon-containing drilling wastes from the oil exploration and production industry onto land. This waste is incorporated into the soil and often these areas are re-sown with a pasture crop in order to facilitate the natural processes which biodegrade, transform and assimilate the waste. Currently landfarmed soils cannot be utilised for dairy as dairy processors stopped collecting milk from these land farms in response to major public concerns about potential health and safety issues. Massey University and Hemp Technologies Ltd are exploring together with the Taranaki Regional Council, Venture Taranaki, oil/gas explorers and affected farmers the application and benefits of growing industrial hemp (*Cannabis sativa* L) as a promising economic and environmental option for these Taranaki landfarms. This project will identify the pathways to grow industrial hemp as a non-food chain commercial end product (e.g. hemp fibre to make so-called 'HempCrete' to build homes), while at the same time improving the quality of landfarmed soils. Controlled glasshouse-based trials of selected cultivars of industrial hemp in landfarmed soils are being carried out to assess potential soil remediation properties and to evaluate crop quality aspects. Extension activities through regional workshop(s) to disseminate the information are planned. This paper will discuss the opportunities and potential for industrial hemp in NZ as promising new cash crop for the Taranaki region and beyond.

Key Words
Land use change, alternative crops, regional development, sustainable building

Introduction
Hemp (*Cannabis sativa* L) belongs to the Cannabaceae family. Hemp cultivars can be classified according to their attributes such as population type (wild or natural cultivars), plant use (fibre or seed cultivars), flowering time (early, mid or late ripening cultivars), gender (dioecious or monoecious cultivars) and geographic origin (Salentijn et al 2015). Industrial hemp is a sustainable and high yielding industrial crop which has been grown around the world for centuries for its fibre, seed or as a dual-purpose crop. There are an estimated 25,000 products made from hemp in the global market (Salentijn et al 2015). The product use are diverse and include a wide-range of (1) fibre/hurd (woody core)-applications from the hemp stalk such as textiles, paper, building materials, industrial products; and (2) nut/oil-applications from the hemp seed such as foods, personal care, biofuel and so on. The history of hemp in NZ is minor compared to indigenous flax (harakeke) (L.) which has been used by Māori as a high fibre plant for textiles use (McPartland et al 2004). Hemp seed was first imported in 1892 and the government trialled hemp in the central North Island in the 1940s but hemp never established as a crop. The Misuse of Drugs Act 1961 outlawed hemp cultivation (McIntosh et al 1998). A change in NZ government legislation in 2001 made it possible to grow industrial hemp under strict licensing laws (McPartland et al 2004). Almost all hemp varieties contain the narcotic compound delta-9-tetrahydrocannibinol (THC). Drug type (marijuana) varieties contain between 3-40% THC (Merfield 1999). Only industrial hemp cultivars on the NZ National Approved List that produce THC levels of <0.3% are permitted to be grown under licence (MoH 2015). Strict regulations regarding THC testing apply for crops grown commercially or for research-purposes, and so far only eight cultivars have been gazetted and approved for NZ (MoH 2015). There are currently 46 registered hemp cultivars in Europe (Salentijn et al 2015). Global interest in the potential of industrial hemp has continued to increase through research and investigations into the uses, sustainability and opportunities for hemp (Amaducci et al 2015). The financial viability of these products will influence whether there is potential for them in markets. Advancements in technology and hemp processing are becoming more widespread and there is an increasing demand for natural fibres in global markets (Bouloc et al 2012). Currently China, Europe and Canada are

the most important hemp producing regions in the world. The commercial production of industrial hemp in New Zealand is relatively new and has mainly focussed on the use of hemp seed oil in the Canterbury region (Townshend and Boleyn 2008).The hemp fibre market in NZ remains somewhat underdeveloped and lacking the processing facilities and farmer interest as seen in the seed oil value chain.

Agronomy

Hemp is an herbaceous annual with a deep tap-root and a single woody stem that can grow to a height of up to 5 metres depending on variety and growing conditions. Hemp plants are originally dioecious, but monoecious varieties also exist (Bouloc et al 2012). Industrial hemp grows well on a range of well-drained soil types and in a range of climates, but it is best suited to temperate conditions between 15°C and 27° (Cole and Zurbo 2008). Hemp requires 1,900-2000°C growth degree days (GDD) to reach fibre maturity and 2,700-3000°C GDD for seed production (Bouloc et al 2012). Hemp is a short-day plant and when grown for fibre production averages to be a 100-120 day crop in NZ where it is generally sown before mid-October and harvested between February and April (Merfield 1999; McPartland et al 2004). Hemp is frost sensitive, but has the ability to grow at low temperatures >1°C (Lisson and Mendham 2000). Plant densities range from 30-70 plants/m^2 (seed production) to 250 plants/m^2 (fibre production) (Van der Werf et al 1995; Cole and Zurbo 2008). Effects of nutrition on yield and quality of industrial fibre hemp is complex, but 120kg N/ha, 100kg P/ha and 160kg K/ha have been reported (Bouloc et al 2012; Cole and Zurbo 2008). Industrial hemp will outgrow weeds when grown under ideal conditions. Hemp fibre crops are densely planted and weed control is generally not necessary, but seed crops with wide spacing may require weed control methods (Bouloc et al 2012). Industrial hemp is known for being pest and disease resistant. Dry stem yields in Europe are reported to be between 8-15t/ha (Lisson and Mendham 2000), and 10-12 t/ha in NSW under irrigation equating to $2,450-2,940/ha with growing costs of $800-1,200/ha (Cole and Zurbo 2008). Since 2001, several oil hemp trials in NZ have been performed by both Midlands Seed Ltd and Plant Research Ltd to evaluate plant growth and yield of cultivars, site location, local climate and agronomic variables such as sowing dates, seed density and fertiliser regime (Townshend and Boleyn 2008).

Production & bioremediation potential for industrial hemp for the Taranaki region

A commissioned report by Venture Taranaki (2014) flagged industrial hemp as one the main opportunities for diversification of the agricultural activity for the Taranaki region (Figure 1), which is currently dominated by the dairy industry as the fourth largest dairy producing region. The growing conditions for industrial hemp in Taranaki are excellent due to ideal local soil and climatic conditions. A targeted level of production and processing of industrial hemp in the region of 1200 hectares is foreseen (Venture Taranaki 2014). Two Taranaki farms are currently licenced to produce industrial hemp. A processing facility is planned to handle the production from 250 hectares of industrial hemp, which will contracted by local growers. Initially only straw for the manufacturing of building material will be processed, but a seed pressing facility is intended as well (Venture Taranaki 2014). Hemp might be grown as a rotational crop with maize for dairy support and has the opportunity to provide a high-returning sustainable diversification option for Taranaki growers and to provide additional employment in the hemp processing sector (Venture Taranaki 2014). The oil and gas industry in Taranaki is another important signature industry, worth $2.8b to the NZ economy (Venture Taranaki 2015). As a result of this oil and gas drilling and exploration, the industry produces a hydrocarbon-containing waste which is disposed of by a practice called 'land farming'.

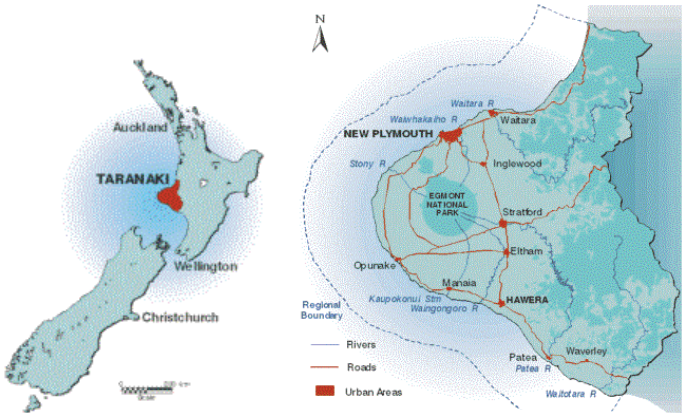

Figure 1. Taranaki region of New Zealand (source: www.safetaranaki.org.nz)

Land farming is a licenced activity of spreading drilling waste onto land and incorporating it into the soil (Proffitt 2013). This is followed by re-sowing the area with a pasture crop in order for the natural processes which stimulate the processes of biodegradation, transformation and assimilation of the waste. Landfarming often targets poor and sandy soils and potentially increases the agronomic value of the land (Edmeades 2013). However, landfarmed soils cannot be utilised for future dairy activities as dairy processors in 2014 stopped collecting milk from these retired land farms in response to major public concerns about potential health & safety issues of hydrocarbon contamination potentially entering the food chain. Phytoremediation is a process where a plant grows on soil, extracts the toxic substances which are accumulated in the upper plant and then can be harvested (Linger et al 2002). Plants grown for these purposes are often annual herbs which have little economic value, but high extraction potential (Linger et al 2002). Although hemp is not considered a hyper-accumulator, it has significant phytoremediation potential due to its high biomass production. Linger et al (2002) looked specifically into the fibre quality and phytoremediation potential of growing industrial hemp on heavy metal contaminated soil and found that the high quality of the fibres and hurds were not affected by heavy metal contamination and the fibre bundle fineness and strength were maintained. In addition to known environmental benefits of hemp to improve soil structure and soil organic matter and reduce erosion and nutrient loss (Merfield 1999), there is considerable potential for hemp production on land-farmed sites its phytoremediation properties due to higher absorbency properties (Linger et al 2002) and as a potential 'mop crop' (Cole and Zurbo 2008). Currently, in a MoH approved pot trial in the greenhouse under controlled conditions, we are assessing the phytoremediation properties of hemp (cv. Fasamo) in comparison with English rye (Lolium perenne L.) in soil extracted from a land-farming operation (Figure 2). Field trials of hemp are planned to assess yield potential and productivity on these land farms.

Figure 2. Controlled pot trial at the Plant Growth Unit of Massey University (Palmerston North) comparing the bioremediation properties of industrial hemp (*C. sativa* right) vs English rye (*L perenne* middle) grown on various soil combinations from a Taranaki land-farm. Control (no plants) left.

Global and local competition

The New Zealand hemp industry may encounter global competition which could affect the viability of domestic hemp production. Strong global competitors are those with a first mover advantage, pre-existing markets and/or those operating with price or scale advantages. Early adopters such as Canada, with established markets, have an advantage over infant hemp producing regions. In Canada fibre production is subsidised by the Hemp Food Industry. Canadian growers also receive a competitive crop income by growing seed for the North American health food market (Bouloc et al 2012). The remaining hemp hurds from the seed harvest can be purchased by processors at a relatively low price, contributing to global competition. The EU is one of the major producers of hemp fibre. Natural fibres such as flax and hemp are becoming more competitive; however they will be dependent on certain EU subsidies. Diversifying production systems in the Taranaki may be challenging due to the dairy domination in the region, however alternative horticultural systems may be more profitable, providing competition for land use (Proffitt 2013). There is a need for hemp fibre to enter product markets through alternative advantages and novel uses, driven by scale of production, yields, transportation costs and market demand (Merfield 1999). Novel uses include using hemp (hurd) mixed with lime ('hempcrete') as a sustainable building material and other applications like animal bedding (Figure 3). To date, the first two houses have been built using hempcrete, with another 20 homes planned within the Taranaki district (Greg Flavall, personal communication). Further investigation of potential product opportunities are critical and exciting options for hemp as key source for nano-cellulose

are currently being developed as spin-off from this initial pilot project. Sufficient local demand will be a key factor in determining the potential for the hemp industry in NZ to expand beyond importation of hemp fibre to local production and local value chain systems.

Figure 3. Hemp construction materials (left; Geiger, 2013) and hemp hurd for animal bedding (right).

Conclusion

There are considerable synergies for using industrial hemp for sustainable source of fibre (and oil) as a promising new cropping opportunity to diversify production systems for the Taranaki region in New Zealand. The potential of hemp as a bioremediation crop grown on local landfarms is currently being assessed and will create a sustainable non-food application which will supply an alternative and environmentally-friendly building material (fibre/hurd) for the district and beyond.

Acknowledgements

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Measuring Farming Practices Used on Cotton Farms

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Abstract
Agronomic management practices used on cotton farms have been monitored through surveys of growers conducted for the Cotton Research and Development Corporation (CRDC). Surveys have gathered information over several years about cotton growing practices, allowing change to be monitored over time to help inform research investment. Since 2013, data has been gathered annually on yields, fibre quality and farmer perspectives on research and extension. In addition, a series of specific agronomic themes have been investigated in detail in different years. These have included nutrition, soils, biotechnology stewardship, weed management, irrigation, energy, workforce, harvesting and riparian areas. This paper reports a small selection of findings from the 2013 and 2014 cotton grower surveys. Cotton grower responses to the 2014 survey covered 27% of the irrigated and 35% of the dryland cotton area grown in the 2013-14 season. The 2013 survey responses represented 23% of the irrigated cotton production area and 27% of the dryland cotton area in 2012-13. This paper describes the survey program and presents a small sample of findings.

Introduction
Information about farming practices and grower perspectives can help inform research and extension efforts. Over the past two decades, a range of research has gathered information on practices used in cotton growing and can be used to monitor change over time. This research for the CRDC and Cotton CRC has included:

- Surveys of cotton growers: 2013-14 (Roth Rural, in press), 2012-13 (Roth Rural, 2013), 2010-11 (GHD Hassall, 2011), 2008 (CCA et al 2008), 2006 (CCA et al, 2007) and 1996-7 (CRDC 2000).
- Annual surveys of cotton consulting agronomists undertaken by Crop Consultants Australia gathering detailed information on crop protection and other issues.
- Financial Comparative Analyses conducted annually by Boyce Chartered Accountants.
- On-farm measurements to benchmark water use efficiency (Montgomery and Wigginton 2012), disease prevalence Kirkby et al 2013) and weed populations (Werth et al 2013).
- Focus groups to assess industry attitudes towards Integrated Pest Management (Coutts et al 2001).
- A convergent interview study on irrigation and knowledge (Callan et al 2004).

Written surveys with telephone follow up have been most effective. The 2011 survey was planned as phone interviews, with the questions mailed out in advance. It was found the majority of respondents preferred to complete the survey form and mail it back. Personal phone calls to invite participation has been essential to achieve adequate response rates.

Method
Questions for the 2013 and 2014 surveys were developed in collaboration with CRDC, Cotton Australia and researchers. In 2013, an open call was made to all cotton researchers for input. Multiple research surveys were combined into one. More recently, the CRDC's monitoring and evaluation framework has guided information needs.

Surveys have focused on the season just completed, investigating a small core of questions annually (yield, crop area, quality) and a further 3-5 themes in detail on a rotating basis. The 2013 survey investigated nutrition, soils, biotechnology stewardship, energy, harvesting, workforce and communications. The 2014 survey explored weed management, irrigation, climate, carbon and riparian areas. Relevant questions have been repeated from earlier surveys to allow data to be compared over time. The intent is to revisit these themes in future years to monitor change. To strengthen the robustness of the data some key questions were investigated over two years to overcome some of the variation in seasons and respondents. For example, information on crop nutrition data was gathered in 2006 and 2007 and revisited in 2011 and 2013.

Surveys were conducted as a written survey, distributed by both mail and email. Respondents could complete the survey on paper or into an online survey tool. Each farm enterprise registered with CRDC (1117 farms in 2014) received by post: a printed survey booklet; a cover letter from CRDC; a snapshot of previous survey data; a stamped return envelope; and a personalised quick response form for recipients to update contact details and indicate if they did not grow cotton or declined to respond. An online survey tool (C-Vent) was emailed – providing growers with an alternate response option and reaching some growers who were not registered with CRDC. This electronic survey tool was used for all data entry.

To encourage a response, industry newsletters promoted the survey and reported previous findings. A prize draw was offered as an incentive. After an initial 3-4 week response window, follow up phone calls encouraged further responses. Survey findings were communicated through reports back to respondents, excerpts in industry media and presentation at the 2014 Australian Cotton Conference.

Determining population size was a challenge as the number of farms growing cotton in any given year is not known. Not all growers registered with CRDC grew cotton in each survey year and not all growers were registered with CRDC. The survey response is considered both in relation to the number of growers registered with CRDC and the total area of cotton grown.

Findings

In 2014, surveys were returned by 177 farms (19%) covering 101,883 ha of irrigated cotton, which was 27% of the national irrigated crop and 14,394 ha, or 35% of the dryland cotton area grown in the 2013-14 season. A total of 420 responses (37%) were received by mail or phone contact, of these 177 returned the survey (124 by mail and 53 online); 144 had not grown cotton in the 2013-14 season and 31 had the survey returned by another on the farm – giving an adjusted population pool of 942 and a response rate of 19%. Regionally, the response rate ranged from 13% in Central Queensland to 21% in Southern NSW. In 2013, 165 surveys were completed, covering 23% of the irrigated cotton area and 27% of the dryland cotton area in 2012-13.

Data rich questions (eg nutrient rates) have required considerable checking to ensure accuracy. The most common inaccuracies have been fertiliser rates recorded in place of nutrient rates and 'per hectare' measures recorded as 'per acre'. These were corrected where possible by calling the respondent.

Yields and quality

Cotton yields in most regions in 2014 were lower than 2013. An exception was Central Queensland where, with relatively dry, sunny conditions, substantially higher yields were achieved in 2014 than in previous wet, cloudy years. In both years there is a substantial difference between the average yield across the region and the highest yielding field recorded for the region, as illustrated in Figure 1 for the 2013-2014 season. The highest yield recorded for a field in the 2014 survey of 15.6 bales/ha was 5.8 bales/ha higher than the average yield across all regions.

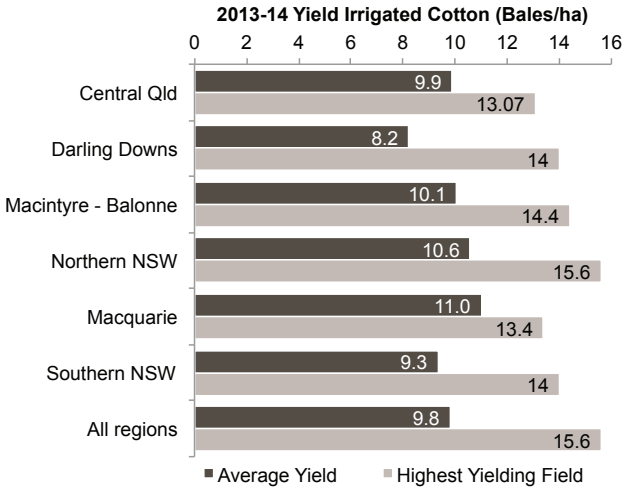

Figure 1 Average and highest yields of irrigated cotton 2013-14

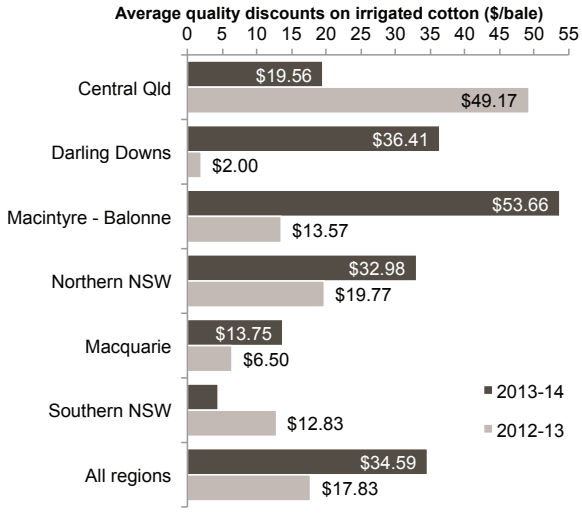

Figure 2 Average quality discounts recorded by region in 2012-13 and 2013-14

Cotton fibre quality is influenced predominantly by weather conditions and insect damage. Figure 2 compares the level of quality discounts reported from the 2012-13 season (dry harvest in most regions, wet in Central Queensland) to the 2013-14 season (wet harvest most regions, dry harvest in Central Queensland). Within regions, some significant differences have been observed in the level of quality discounts recorded on different farms, with potentially large implications for profitability.

Nutrition

Nutrient rates as applied fertiliser were gathered using similar categories to previous years, allowing the rate of applied nutrients to be compared from 1997 – 2013 (Table 1). The overall increase over time can likely be largely attributed to increases in cotton yields. However, the high variability in rates used on different farms in 2013 was not correlated with yield. 29% of respondent farms applied between 200-250 kgN/ha and 27% applied more than 250 kgN/ha. The most commonly given reasons for higher nitrogen rates were "the crop needs more N to achieve high yield" (75% of respondents) and "the agronomist recommended it" (41%). In 2013, 13% of respondents achieved a nitrogen fertiliser use efficiency within the optimum range of 12.5 to 16 kgLint/kgN recommended by research.

The 2013 survey also gathered information on timing and method of fertiliser application, the use of soil testing and other decision factors. On average, 67% of nitrogen is applied pre-season with 50% of farms applying between 30 and 70% of nitrogen pre-season. A diversity of application methods were used.

Table 1. Nutrient rates in fertiliser applied to irrigated (IRR) and dryland (DRY) cotton, 1997-2013

FERTILISER	1997	2001*	2006*	2007*	2011^ IRR	2013 IRR	2011^ DRY	2013 DRY
Pre-season nitrogen - solid (kg N/ha)		80	87	101	142	135	89	89
Pre-season nitrogen - gaseous (kg N/ha)		78	71	60	155	169	84	70
In-season nitrogen – solid (kg N/ha)		17	29	60	99	100	45	33
In-season nitrogen – gaseous (kg N/ha)		8	14	18	83	88	40	-
In-season N water applied (kg N/ha)					57	61	5	-
TOTAL applied N kg/ha	125	176			217	243	96	84
Pre-season phosphorus (kg P/ha)		23	30	35	42	31	14	14
In-season phosphorus (kg P/ha)		*2*	3	2	20	15	13	8
TOTAL applied P kg/ha					40	31	16	13
Pre-season potassium (kg K/ha)		8	16	24	33	26	7	10
In-season potassium (kg K/ha)		0	2	4	15	12	2	-
TOTAL applied K kg/ha					28	24	7	10
Zinc (kg Zn/ha)		5	5	5	4.4	3	3.7	1.8
Sulphur (kg S/ha)					6.3	14	2.4	5.5
Trace elements					21	9	4	-

* Roth G (2009) Economic, environmental and social sustainability indicators of the Australian Cotton industry. Cotton CRC.
^ GHD Hassall (2011) Cotton Grower Practices Survey. Cotton CRC and CRDC.

Weed management

Glyphosate management to minimise herbicide resistance is a key focus of cotton research and extension efforts in the area of weed management. To coincide with the release of the first Cotton Herbicide Resistance Management Strategy (HRMS), the 2014 survey gathered information to benchmark current weed management practices. Questions were asked about the weed management tactics used in a given irrigated and/or dryland field over a 12 month period. Analysis of individual responses determined the mix of weed control tactics used to compare with the HRMS recommendations.

79% of respondents were consistent with the HRM recommendations, using two or more non-glyphosate tactics to manage weeds in an irrigated cotton field from July 2013 - June 2014. 4% of respondents used only glyphosate. In dryland cotton, 63% of respondents used two or more non-glyphosate tactics to manage weeds while 7% used only glyphosate. 73% of all respondents indicated they would tolerate less than 5% weed survivors after the first over the top glyphosate application on Roundup Ready™ cotton.

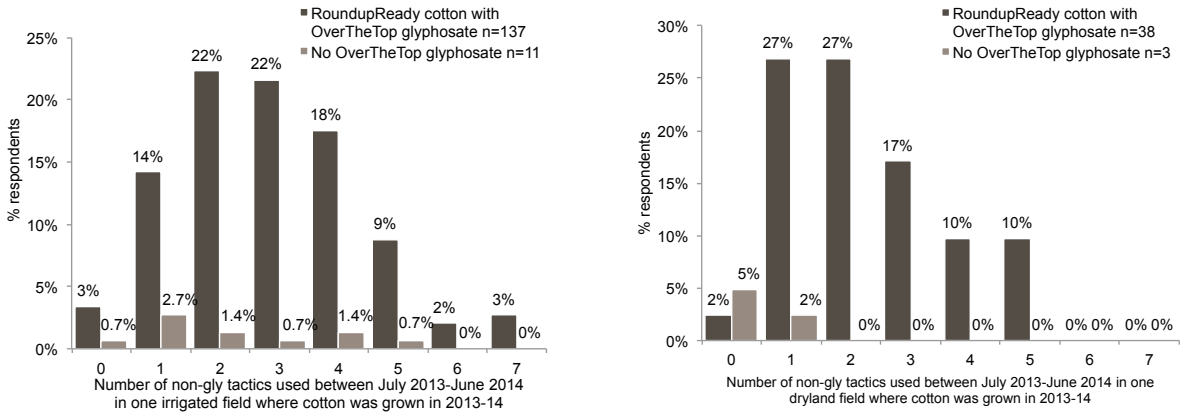

Figure 2. Proportion of farms using the number of non-glyphosate tactics to manage weeds in a irrigated cotton (left) or dryland cotton (right) field for the 12 months from July 2013-June 2014

Irrigation

From 2006 to 2011 there was a 30% increase in the use of soil moisture probes for irrigation scheduling. The use of irrigation scheduling tools showed little change between 2011 and 2014. 28% of respondents in 2014 indicated they had more than one type irrigation system on their farm. Furrow is the dominant irrigation system, with 8% of the cotton area grown under other irrigation systems in 2013-14. Table 2 shows that while 19% of respondents had lateral move irrigators, just 3% of the irrigated crop was grown under lateral moves.

Table 2 Irrigation systems used on cotton farms in 2013-14

	Furrow (excluding bankless)	Bankless Channels	Centre Pivot	Lateral Move	Drip
% respondents using this irrigation type	95 %	11 %	16 %	19 %	8 %
% of cotton area grown under system 2013-14	92.1 %	2.5 %	1.7 %	3 %	0.7 %

Conclusions

Regular surveys of cotton growers have gathered information about a range of farming practices. The information can be used to identify areas for extension effort and the industry has used the information in policy activities and for the Cotton Industry Sustainability Report. Future surveys can build on the data set.

Acknowledgments

Thank-you to the cotton growers who shared their information through the survey and to CRDC for funding.

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Comparison of stubble management strategies in the high rainfall zone

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Abstract

Heavy crop stubble loads in the high rainfall zone are a consequence of higher grain crop yields compared with other grain growing areas of Australia. A stubble management trial was established in northern Tasmania to evaluate different stubble management options. Five stubble management strategies were compared: stubble fully retained; fully retained with higher sowing rate; incorporated; cut and removed; and burnt. The trial was a randomised complete block design with four replicates and large plots, 50 by 8 m. This paper reports on wheat growth and grain yields for the 2010 season. Full retention of stubble resulted in greater soil moisture early in the season and higher earthworm and slug populations. Plant establishment is commonly a problem with full stubble retention. The higher sowing rate treatment resulted in a correspondingly higher plant establishment and dry matter production at harvest. There were no significant differences in grain yield.

Key words

Direct drill, stubble retention, conservation cropping

Introduction

Minimum tillage and stubble retention practices have been widely adopted due to a number of benefits in particular reduced fuel and labour costs, soil moisture retention and reduced soil erosion (Kirkegaard, 1995; Scott et al., 2013). However, in practice adoption is generally more opportunistic due to issues including machinery trash flow, reduced crop establishment and pest and disease problems (Scott *et al*., 2013). In the high rainfall zone, such as Tasmania, the generally greater crop yields result in additional stubble residue loads further exacerbating these problems. Slugs in particular have become an increasingly major problem. Growers in these areas recognise these issues and will accordingly alter their practices to accommodate the situation. Thus while burning of stubbles prior to sowing the next crop is not common due to environmental and other disadvantages, when there is a large stubble load, burning may become a necessary strategy. For example, with increased seasonal rainfall and additional crop growth the frequency of burning to reduce crop stubbles in Tasmania increased to 36% in 2011 (Edwards *et al*., 2012).

There are a number of alternative practices to assist with excess stubble residue. The aim of this trial was to compare the effects of different stubble treatments on crop establishment, growth and grain yield. The sustainability of treatments was also evaluated with comparison of soil physical and biological characteristics.

Methods

Location, treatments and experimental design

The trial site was established at Perth, Tasmania (41°37'S, 147°15'E) in 2006 as a long term stubble management experiment. The soil is a brown sodosol with a fine grey sandy loam to 25 cm overlying a heavy clay subsoil. The trial had a previous history of wheat, tickbeans, wheat and most recently, canola. Plots were 50 by 8 m with four replicates in a randomised complete block design. Before commencing the trial, discussions to select treatments were held with farmers and advisors. Five stubble treatments were selected: stubble fully retained (SFR); stubble fully retained with a higher sowing rate (SFR + HSR) [prior to 2009 this treatment was incorporation with offset discs]; stubble incorporated with Lemken discs (SI); stubble cut to 150 mm with a windrower and removed from plot (SRC); and stubble removed by burning with a 'cool burn' in autumn (SRB). Herein results of the trial in the 2010 season are reported.

Management and measurements

The trial was sown with Revenue wheat on 24th May at 85 kg/ha (115 kg/ha for SFR + HSR) using a Baldan disc drill. Weeds and pests were controlled as required and two top-dressings of nitrogen (total of 100 kg N/ha) were applied. Growing season rainfall (Apr-Nov) was 502 mm with an additional 150 mm irrigation applied over flowering and grain fill.

Ground cover, establishment counts, soil temperature, gravimetric soil moisture content, penetrometer (Rimik CP20) and weed counts were taken. Additional observations of invertebrate populations and soil fauna biomass were conducted in SFR and SRB plots. Pitfall traps (2 per plot) constructed from plastic tubs containing ethylene glycol, were inserted at ground level and monitored every 14-21 days. Spade tests (5 holes/plot) were dug to assess changes in populations of earthworms. Bacterial and fungal biomass levels were determined by the Soil Foodweb Institute, Lismore. Prior to machine harvest at maturity, dry matter cuts (8 x 0.25m^2) were taken from each plot.

Differences between treatment effects were analysed by ANOVA (Genstat 17, VSN International Ltd). The least significant difference (LSD) was calculated at P = 0.05 for testing differences between treatments.

Results and Discussion

Above average rainfall in the 2010 season in northern Tasmania, particularly over winter and spring, resulted in much of the trial area being waterlogged for extended periods. June in particular was very wet (Decile 8-9). Additional high rainfall over flowering and during grain fill coupled with the supplemental irrigation resulted in limited soil moisture stress during this period.

Stubble residue from the 2009 season canola was low due to a poor yielding crop but there was visually higher stubble residue in the two stubble fully retained plots compared to the other treatments (Table 1). Plant establishment was increased with the higher sowing rate although this was not different to the SI treatment. There was no difference in plant establishment between SI, SRC, SFR and SRB plots (Table 1). In the current trial low stubble loads resulted in minimal sowing problems but Kirkegaard (1995), reviewing previous stubble field trials, notes the common problem of establishing crops with retained stubble. The ground cover scores broadly correlated with soil temperature and reflect the degree of shading. At early establishment the two treatments with the highest residue cover (fully retained) resulted in significantly lower soil temperatures compared with other treatments (Table 1). There were no temperature differences between treatments when the plants were at early stem elongation (data not presented).

Table 1. Effect of stubble management treatments; SFR (stubble fully retained), SFR + HSR (stubble fully retained, with a higher sowing rate), SI (stubble incorporated), SRC (stubble removed, cut) and SRB (stubble removed, burnt), on surface straw, plant establishment and soil temperature (16th June).

Treatment	Surface straw scores 0 (none) – 10 (high, approx. 4 t/ha)	Plant density 1st July (plants/m^2)	Soil temp at 5 cm (°C)
SFR	6.3	104	7.7
SFR + HSR	5.5	124	7.9
SI	2.3	114	8.5
SRC	1.0	106	8.3
SRB	1.5	103	8.4
P value	<0.001	0.007	0.001
$LSD_{0.05}$	1.6	11	0.3

Consistent with other studies e.g. Kirkegaard *et al*., 2001; Scott et al., 2013, there were differences in soil moisture at the beginning of crop establishment. At 40-60 cm depth this difference was significant (P = <0.001) with gravimetric soil moisture content higher in both the stubble fully retained plots (33.7%) compared with SRB and SI treatments (27 and 25.5% respectively, data not presented). The difference at this lower depth was probably carry-over from the previous season. However the soil moisture content was not significantly different between treatments at any other measurement dates (data not presented), likely due to the high rainfall throughout the season masking treatment soil moisture differences.

Penetrometer measurements were taken at crop GS32 when the soil was at soil field capacity. Measurements were made at 0-100, 100-200 and 200-300 mm depth intervals. Penetration resistance was significantly lower for both the SI and SFR +HSR treatments compared with the SFR and SRB treatments at the 0-100 mm depth (Figure 1). The effects of mechanical tillage on soil strength in the SI and the SFR + HSR plots (disced until the previous season) were thus greater than any other stubble management practices.

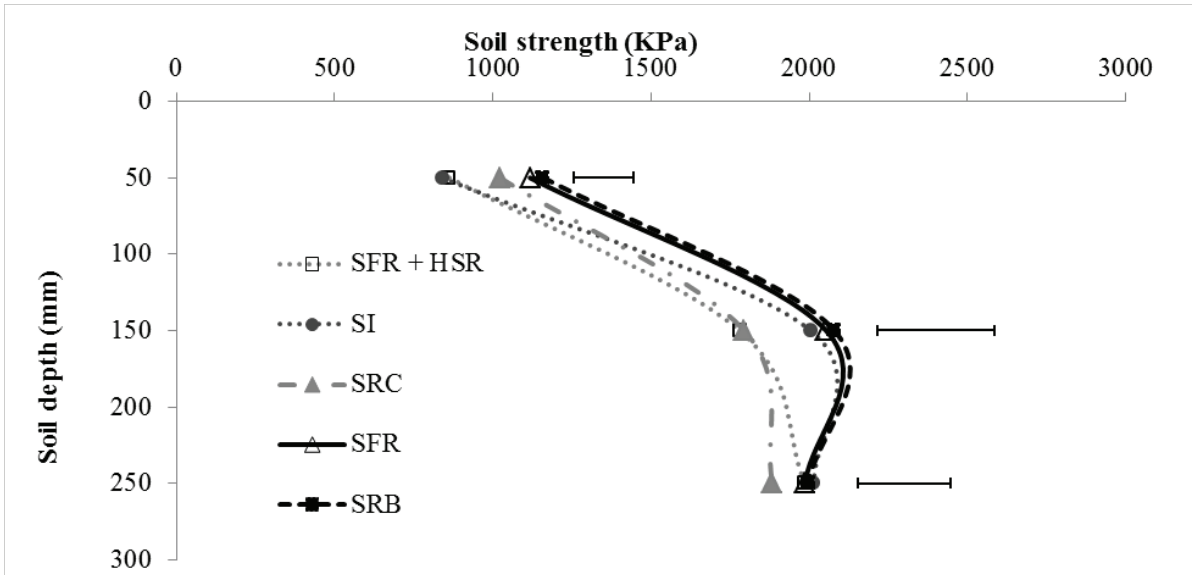

Figure 1. Effect of stubble management treatments; SFR (stubble fully retained), SFR + HSR (stubble fully retained, with a higher sowing rate[previously disced]), SI (stubble incorporated), SRC (stubble removed, cut) and SRB (stubble removed, burnt) on soils strength (KPa). Bars represent LSD (0.05).

With weed populations, toadrush (*Juncus bufonius*) density varied between plots with the stubble fully retained plots showing the lowest populations (Figure 2). These weeds were probably symptomatic of the observed higher incidence of waterlogging and surface water in the plots where stubble had been removed or incorporated. There were no differences between treatments with the populations of other weeds in particular ryegrass (*Lolium rigidum*), sub clover (*Trifolium subterraneum*), spear thistle (*Cirsium vulgare*) and field madder (*Sherardia arvensis*) (data not presented).

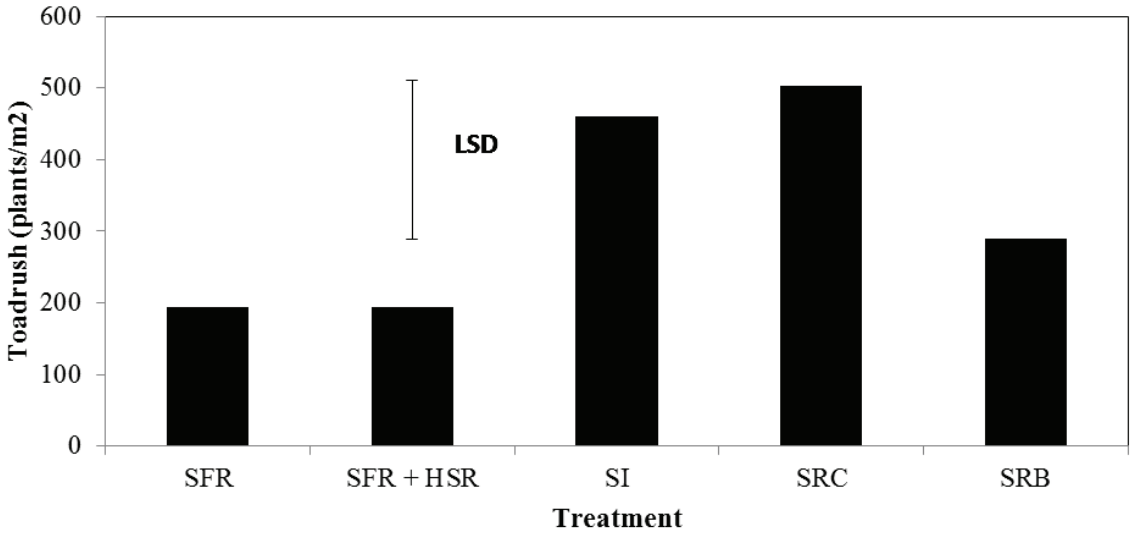

Figure 2. Effect of stubble management treatments; SFR (stubble fully retained), SFR + HSR (stubble fully retained, with a higher sowing rate), SI (stubble incorporated), SRC (stubble removed, cut) and SRB (stubble removed, burnt), on plant density (plants per m2) of toadrush (*Juncus bufonius*). Bar represents LSD (0.05).

Earthworm and slug numbers were higher in SFR compared with SRB plots (Table 2). Bacterial and fungal biomass levels were in the desired range according to Soil Foodweb Institute; however there were no differences between treatments (Table 2). There were also no differences in the biomass of other soil fauna tested, namely flagellates, amoebae, ciliates or actinobacteria nor the ratio of bacteria to fungi between treatments (data not presented). Kirkegaard *et al*., (2001) reported higher populations of earthworms but also increased microbial biomass. It is possible the very wet conditions in the current trial were detrimental to microbial biomass. The negative effect of increased slug numbers with stubble retention has been highlighted elsewhere (Scott *et a*l., 2013).

Table 2. Effect of stubble management treatments; SFR (stubble fully retained), and SRB (stubble removed, burnt), on invertebrate populations and microbial biomass.

Treatment	Spade test (average)	Tile trap (average)	Total bacteria	Total fungi
	earthworms	slugs	(µg/g)	(µg/g)
SFR	5.8	9.3	96	245
SRB	1.1	3.3	111	191
P value	0.001	0.027	ns	ns

Dry matter production from the different treatments prior to harvest were comparable between treatments aside from the SFR + HSR plots which produced significantly higher biomass than other treatments (Table 3). Although not significant (P=0.08) this difference tended to carry through to final grain yield (Table 3). Poorer establishment with full stubble retention is commonly observed (e.g. Kirkegaard, 1995; Scott *et al*., 2013) and the early effects on plant density with the higher sowing rate may alleviate this. Under the wet seasonal conditions plant tillering was likely to have been reduced and thus the benefit of the higher sowing rate more likely to be expressed. In previous trials at the site (2006, 2008), plant establishment and grain yield of wheat have both been negatively affected by retained stubble compared with burnt plots. In contrast in the current trial, plant establishment, dry matter production and yield of the SFR treatment was not significantly lower, again suggesting the importance of adequate initial plant establishment.

Table 3. Effect of stubble management treatments SFR (stubble fully retained), SFR + HSR (stubble fully retained, with a higher sowing rate), SI (stubble incorporated), SRC (stubble removed, cut) and SRB (stubble removed, burnt) on dry matter production at harvest and grain yield.

Treatment	Dry matter at harvest (t/ha)	Grain yield (t/ha)
SFR	14.5	6.1
SFR + HSR	17.5	6.7
SI	15.1	5.8
SRC	15.3	6.1
SRB	13.8	5.3
P value	0.027	0.076
$LSD_{0.05}$	2.08	-

Conclusions

Full retention of stubble resulted in increased soil moisture early in the season and higher earthworm populations. There was also an increase in slug numbers with retained stubble. There was no effect of stubble management on grain yield; however the higher sowing rate tended to increase yield compared to other treatments. The increased sowing rate also resulted in higher plant establishment and dry matter production at harvest suggesting the importance of this factor in alleviating lower yields commonly associated with full stubble retention.

Acknowledgments

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Back to the future. Big data opportunities for Australian grain growers

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Abstract
There has been much said about the potential for Big Data breakthroughs in all industries, This paper explores the necessary thinking, data structures and convergence required to make accessing Big Data information on field trials for Australian grain growers a reality. It then goes further by suggesting a possible structural model that could be used to access the power of Big Data. The paper identifies that potentially investment in some of the core infrastructure has already potentially been made. We just need good leadership and a relatively small amount of additional investment to harness the benefits.

Key words
Big data, Australia, Grain growers, opportunities,

Introduction
Wikipedia defines "Big Data" as "…so large or complex that traditional data processing applications are inadequate… beyond the ability of commonly used software tools to … process data within a tolerable elapsed time."

Putting aside jargon, Freakonomics is a great place to start examining the power of big data. It demonstrates the power of Big Data in entertaining ways including how to find bank robbers, direct emergency services and whether or not your child's name determines its success in life. On the darker side, Freakonomics will help explain why you probably won't be punished for running someone over in New York.
"Big data" for the grains industry is too big a topic for a single presentation. The focus in this paper is ultimately grower access to "big data" from field trials in Australia and making informed farming decisions. Field trial data is meaningless unless it underpins credible "information" which answers the right questions. Field trials assess the performance (or performance potential) of varieties, so the "right" question becomes: "Are there other varieties I should consider which have potential based on my location and circumstance." Whilst by no means the only credible source of data in the grains industry, the NVT Online Database has about 4 million GPS-based data points from about 5,000 trials, variety passport information and a further 20 million tiny tag temperature data points available. As it takes 2 weeks to count to a million, it would take a year to read all the data. Let's just say the size of the NVT database is big.

Materials
Data Credibility, Accessibility and Ownership
In the late 90's, 20 varieties could be ranked across a number of credible field trials. It is worth telling a story first to outline an important principle.

A few years ago a variety from "Company AA" ranked in position seven. In their glossy sales brochure they showed the same table of results, but omitted varieties 1 through 6, showing only 14 varieties, where now their variety was at the top of the table. This type of marketing makes it nigh on impossible for growers to make the right decisions. Was this illegal? No. Misleading? Definitely.

Growers must be able to trust the data they receive is clearly presented and unbiased which is underpinned by accredited processes and analysed with scientific rigour. GRDC funded initiatives, like NVT, as opposed to data from the commercial sector, give growers confidence in the data presented.

NVT field trial processes are accredited. Service providers and ACAS staff are unbiased in their collection, handling, analysis and publication of data. Data imported into the system undergoes similar rigour. Lack of potential for conflict of interest is essential.

The end-to-end accredited process of NVT data capture, analysis and release is currently the optimum for producing credible big data in the Australian grains industry. The processes and systems have underpinned a decade of national data collection and reporting. This framework is an example of a "data custodian" model, facilitated by GRDC, that ensures the data and reports are credible. This means growers can, without fail, trust the information derived from NVT.

Therefore, to increase the amount of "trustworthy" data and information available to growers , the experience, processes and system in place for NVT should be further expanded to the benefit of Australian growers and researchers.

Data Divergence – Undermining Data Value and Reinvestment
The more data that feeds back into a central store or database, the greater the value of the existing and new data. A simple analogy is to think of it as being more cross referenced, used and connected. Data "investment", "leverage" or "value adding" is best achieved using Big Data methods.

When data diverges away from the centre, it "disconnects" and its value is lowered.

Another example might be helpful. Let's say we performed ground breaking research and only produced a book. The book could even be a PDF, which in most cases, is just a digital, non database publication. We could read that book and understand its logic, but unlike a database or system, the data or information inside cannot be readily analysed. Nor can any of the developing Big Data analytical tools for querying, analysis, import, export or combination be used.

But even for data in a database, in the same format, divergence can still occur. In the early 2000's, the "Variety Selector" CD-ROM attempted to combine data from across borders from SA and WA. There was no questioning the credibility or rigour of the work in each state. However, the analytical models varied so much the data could not be compared. A "7" in a field from across the border may not be the same as a "7" defined locally.

So these state based, valuable, worthwhile and important research projects were underpinned by potentially great, but stand alone data collection system. This produced "fragmented" data. This continues to occur across field trial projects today. Divergent systems producing divergent data. There is significant value to be gained if the data was part of a bigger data store.

Ideally, all data would be captured at the source using standard tools via accredited and approved national practices. The "ideal" doesn't yet exist; politics, partnerships, state borders, contracts and competition get in the way. But until we move closer to it, the value of research outputs can't be leveraged back into a broader, big data community and the true value of R&D efforts won't be realised or understood.

Results
Promoting Data Convergence and Reinvestment
To maximise the value of collected information, results and data, there needs to be a paradigm shift in the way it is collected and managed. Rather than using stand-alone tools, embracing open access platforms, based on existing best practice methodologies, could be used. As an industry we have a habit of fiddling with data sources by using things like spreadsheets. They degrade data value. There are far better ways. Intellectual property can still be protected whilst sharing information such as, variety name histories, soil test results, rainfall data, disease measurement scales and active ingredient concentrations in pesticides. Existing methodologies could significantly improve data quality, decrease errors, promote optimum data fidelity and increase the size of a big data pool to all projects which used and contributed.

There are some fantastic applications which report on crop variety performance; beautiful interfaces that encourage interrogation of varietal parameters with data that is three years old. They look brand new, shiny and the wow factor is immense. Applications, like books, risk being outdated the moment they are approved. The "ideal" report is accessible, answers the right questions, has up to date data and interconnects with other

information. An essential part of R&D is competition and innovation. In this sense, we need innovation in not just research, but the way we view the data. But we don't have to reinvent the process wheel.
This data custodian model or framework, which could be facilitated by organisations like GRDC, promotes shared access of trial data that feeds back into a big data pool and provides acceptable control of access to data. Standard input and processing leads to data which can be analysed. Now I should say words like "standardised" and "centralised" send chills down the spine of researchers. But it should not. These models are not about constricting creativity but about promoting best practice and focussing on research outcomes. We are in effect, going back to the future.

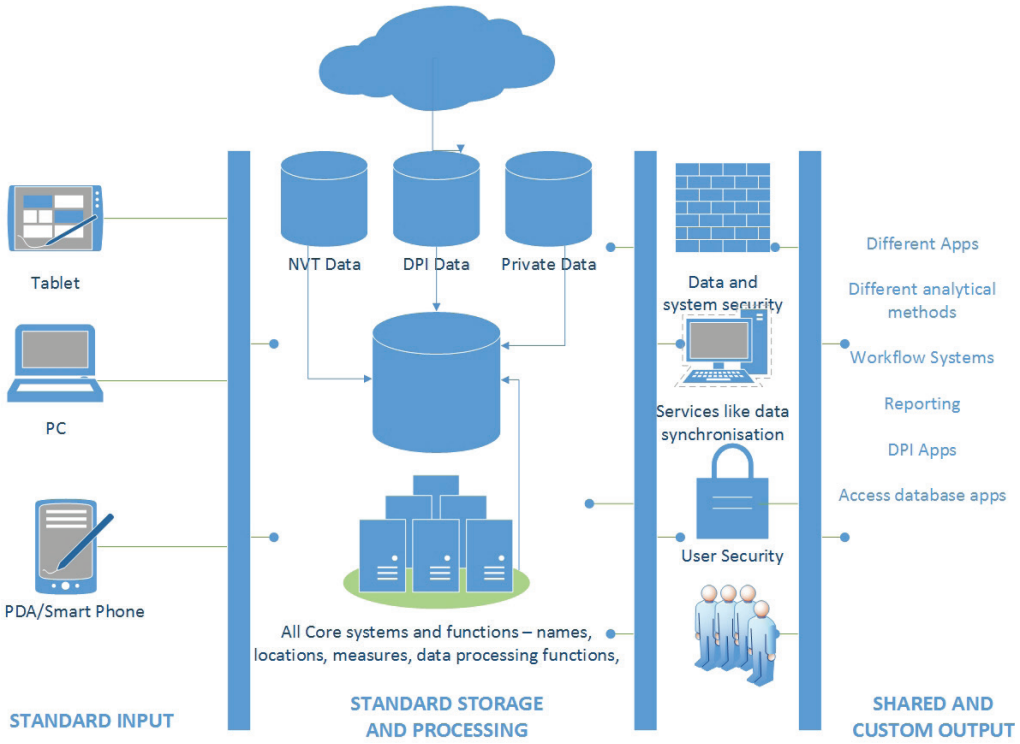

Figure 1 : An example of an Optimal Big Data model for the grains industry

The example given of an Optimal Big Data model in Figure 1, highlights the need for a central database with flexible data entry and even more flexible reporting access and options.

As a means of comparison, the team who out together the significant data comparisons and numerous publications at Freakonomics.com, have the one central data repository. At last count, they had long since removed any spreadsheets from their building!

The benefits for research and results for growers are:

- Data is up-to-date, centralised, not fragmented, converges and gets bigger
- Significantly faster development timelines and return on investment for projects leveraging the big data pool
- Significantly reduced development and data management costs

And the benefits for growers are a further depth of knowledge, based on more data produced by accredited means, that is easier to understand and enable them to make better and more profitable farming decisions. Researchers can also benefit by adopting the best practice tools on the basis that better tools should facilitate more productive work. The value delivered by researchers is higher when their output is delivering value to a broader audience. The more researchers who use a framework like this means there is a greater chance their R&D outcomes will reach their full potential. That's generally handy when going for another research grant. The more centralised the data becomes, the more data that goes into one place, the more powerful that every application that accesses this data can be, the greater the knowledge that can be drawn from each investment leveraging the "big data" ideology.

Conclusion

In the 80's mobile phones were considered too expensive for use. In the 90's there were doubts over the value of the internet. In 2010, the doubters said growers would never have need for an iPad. There are still some that question the need and investment required for Big Data. Technology has a habit of making fools out of very many seers.

Yet, the challenges facing Australian agriculture over the coming decades, including climate change, are huge. Untapped opportunities for many Australian agricultural R&D outcomes remain unknown.
The good news is that there are significant data models, following world best practices, which are running and being utilised today. The NVT Online program is a great example. Big Data is not about reinventing the wheel, it is about reconnecting and finding value from leveraging existing well planned investments. We have the backbone, what we need is leadership and visionaries to link what we have in a meaningful way. Many industries, including agriculture, have begun their journey towards a big data future. We've identified better ways of doing things; it's time to discuss making the most of them as opposed to resisting change because of which side of the border we live on or who funds our project.

What we do know is the way ahead lies outside a spreadsheet. It lies in embracing big data.

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Soil-landscape effects on plant available water capacity (PAWC)

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Abstract
Soils differ in the amount of water they can store and release to different crops, which is captured by the Plant Available Water Capacity (PAWC). More than 1000 soils around Australia have been characterised for PAWC. Interpreting and extrapolating from this point-based dataset requires an understanding of the factors that determine the PAWC. In this paper we use case studies from different environments to illustrate how knowledge about soil-landscape associations can explain PAWC profiles and clarify differential crop performances and management needs. We also consider possible sources of soil-landscape survey information that may be explored to extrapolate PAWC information.

Key words
Soil characterisation, landscapes, water holding capacity, dryland agriculture, APSIM, soil survey

Introduction

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, which is contributed by in-season rainfall and stored soil moisture. The amount of stored soil water available to a crop, Plant Available Water (PAW), is affected by pre-season and in-season rainfall, runoff and evaporation, but also strongly depends on a soil's PAWC, which is the total amount of water a soil can store and release to different crops. CSIRO, in collaboration with state agencies, catchment management organisations, advisors and farmers has characterised more than 1000 soils around Australia. This information is compiled in the APSoil database (http://www.apsim.info/Products/APSoil.aspx) and accessible through, e.g. Google Earth. Farmers and advisors can use this information along with an assessment of PAW at sowing to gain an understanding of the amount of soil water that may be available to the crop and use this to forecast yield and inform fertiliser management decisions.

The PAWCs have been determined using a field based method characterising the Drained Upper Limit (DUL) and crop lower limit (CLL) (see Burk and Dalgliesh, 2013). While robust, the method is time consuming and locality specific, so that farmers and advisors face the challenge of extrapolating from this point based data to their own paddocks. PAWC varies with the soil's hydraulic properties, but because it is modified by the crop's rooting depth it is also modified by subsoil constraints such as salinity, sodicity, acidity, bulk density and soil depth. As the soil physical and chemical properties are tightly linked to a soil's development and position in the landscape and these same aspects underpin soil and land resource surveys, there is an opportunity to explore whether existing soil-landscape mapping can be used to predict PAWC. The objective of this paper was to explore using three initial case studies the feasibility of using soil-landscape information to explain PAWC profiles and extrapolate from point-based PAWC data.

Materials and Methods

PAWC characterisations in three regions representing different environments were compared with available information (see list (*) of tools under References) on soil type, land form and soil-landscape information.

Results

Case study 1: Four soils were characterised for PAWC in the rolling, granodiorite hills near Young, NSW. The soil's position in the landscape, including being on a shorter, steeper slope or a longer, gentle slope affected their soil profile development and matched the soil-landscape unit description in ESpade*. Information on texture, particle size analysis, colour, presence of mottling, exchangeable sodium content explained the soil forming processes and the resulting PAWC profiles. The soil properties, along with PAWC, explained the farmers' observations on differential performances and management needs (Figure 1).

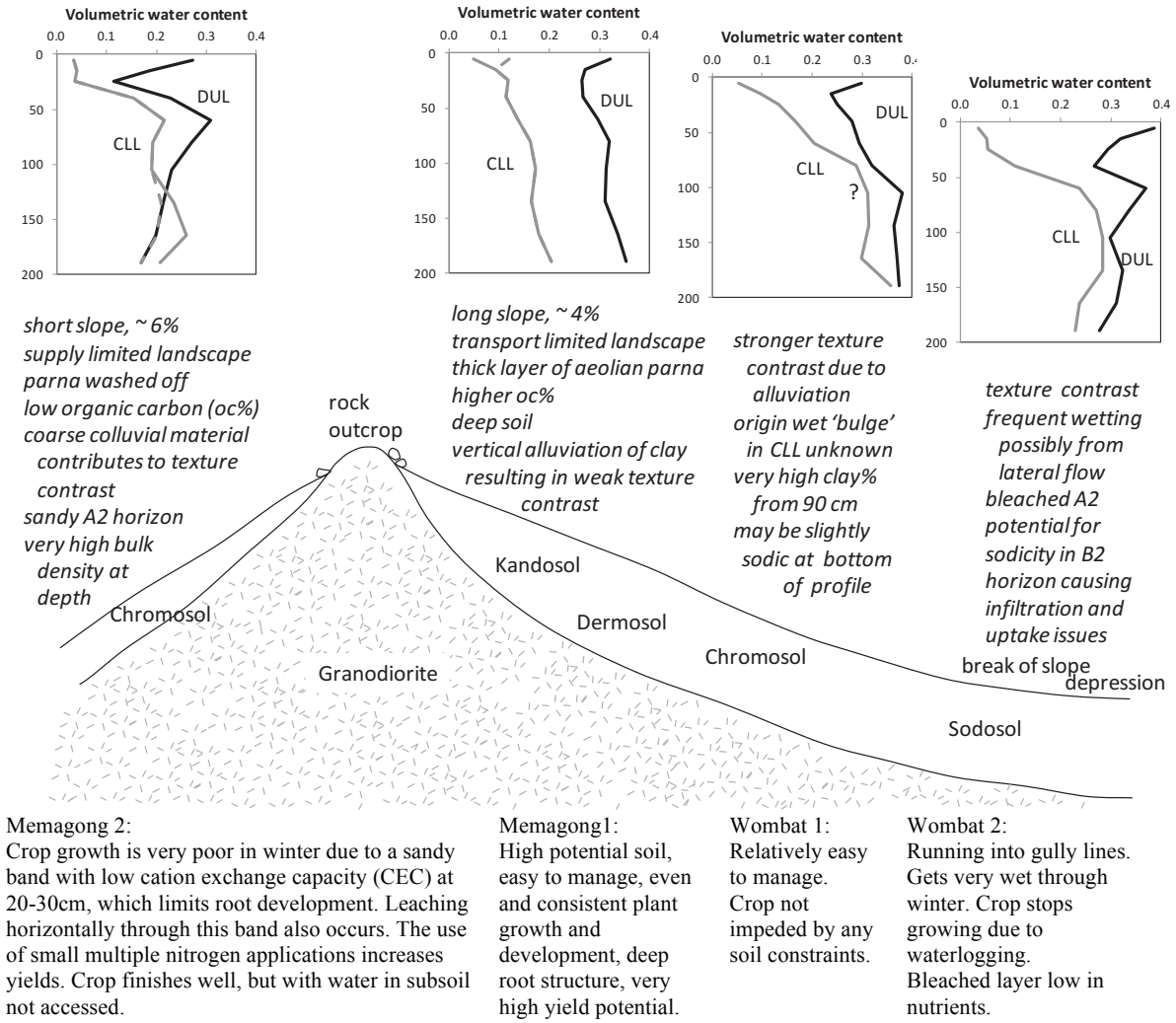

Figure 1. Schematic linking four different PAWC profiles, associated chemistry and their management implications to relative slope positions in the Young granodiorite hills (source: Verburg et al. 2015 with soil landscape diagram based on the diagram and description of Young (yo) soil-landscape unit in ESpade*).

Case study 2: The Central Darling Downs in Southern Queensland are well covered by field measured PAWC characterisations (31) as well as having a long history of land resource assessments. A Land Management Manual (Harris et al. 1999) synthesized the available land resource data using mapping of land resource areas (LRA) as its basis. The LRAs were defined as "broad landscape units made up of groups of different soils developed from related geological units with recurring patterns of topography and vegetation", similar to definitions of soil-landscape mapping used elsewhere. The features of the soils (68) identified within these LRAs were described in detail along with landform, vegetation and land use related information. This included a predicted PAWC class in 50 mm intervals from < 50 to > 250 mm, which is a level of uncertainty that is probably acceptable for opportunity cropping decisions, certainly on the heavier soils.

APSoil site locations were located on the LRA map and where APSoil soil descriptions permitted linked to one of the 68 soil types. The field measured PAWCs were compared with the PAWC class for the identified soil type. Field characterisation often resulted in different PAWC for different crops. For example, the difference between cotton and sorghum ranged from -25 to +85 mm, with an average of +25 mm. This may relate to the crop's rooting depth, but could also reflect uncertainty due to seasonal differences (if measured in difference seasons) and spatial soil variability. Despite this uncertainty there was a reasonably good match between the measured PAWCs and the predicted PAWC classes, with the distinction between >250 mm black vertosols and 200-250 mm grey vertosols reflected in the field measured PAWCs. The relative magnitude of the PAWC of different soil types could be explained through land forming process and parent material (captured by LRA) and position within the LRA (e.g. slight rises within plains). In the LRAs representing the plains, tree species also provided clues with PAWC of grassland > poplar box > brigalow.

Case study 3: In the Victorian and SA Mallee the APSoil database contains several examples of contrasting PAWC profiles from different landscape positions in the dune-swale land type systems. PAWC profiles for dunes generally have a narrow but deep APSoil profile typical of deep sandy soils, except where the dune is overlaying limestone deposits. On the swales the PAWC has a wider 'bucket' typical of clay or clay loam soils, but these soils are often constrained at 60 to 100cm depth by salinity, sodicity and high pH. While difficult to interpret due to the frequent lack of landscape position information in the APSoil database, the PAWC for dune sands typically is of the order of ~80-120 mm, and that of the swale ~140-200 mm, the latter being strongly determined by the strength and depth of the subsoil constraint. The dune soils are also characterised by lower organic carbon and cation exchange capacity (CEC), leading to lower fertility. Management implications are primarily based on the low PAWC for the dunes with barley being grown as a preferred crop, and subsoil constraints in the swales which restricts crop selection with pulse crops being more constrained by subsoil limitations than cereals.

While conceptually appearing to be a simple system, multiple superimposing land forming processes with sometimes counteracting effects (Tertiary sediments capped by calcrete and then covered by windblown deposits of two separate formations and subsequent soil forming processes) have resulted in a significant level of micro variation which expresses itself in terms of, for example, depth to sodic layers and toxic concentrations of boron, presence of gilgais, and depth of limestone and topsoil. In the case of an experimental site near Karoonda, SA, the within-paddock variation in PAWC characterised by three soil characterisations associated with dune, mid-slope and swale positions was confirmed by the description of the soil-landscape unit and its soils (Hall et al. 2009). Landscape attribute information contained in the recently released version 1 of the Soil and Landscape Grid of Australia* proved insufficiently detailed in this district to map the low dunes and shallow swales at the paddock scale. The predictions of some of the soil attributes appear to pick up on some of the dune-swale patterns suggested by the Google Earth image (Figure 2), but the spatial resolution (90 m x 90 m) is just not fine enough. Available soil water is not a good predictor yet in this district.

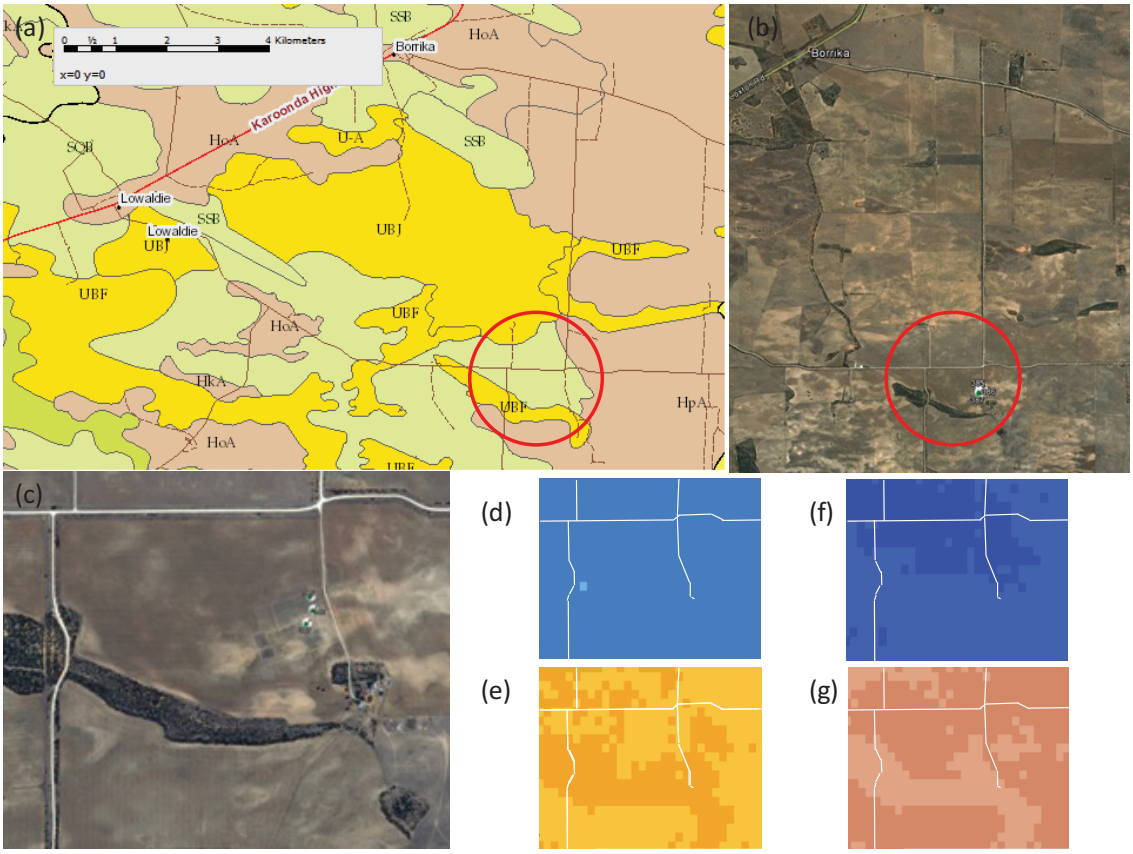

Figure 2: (a) Soil-landscape units from SA State Land and Soil Information Framework on NatureMaps*, (b) Google Earth image indicating the paddock with (c) three PAWC sites located on the experimental trial and shallow dunes just visible; predicted (d) Available Soil Water, (e) (national) sand content and (f) pH at 60-100 cm depth, and (g) organic carbon content at 0-5 cm depth (data from Soil and Landscape Grid of Australia v1*).

Discussion

The three case studies demonstrate a number of points:

The examples demonstrate clear associations between landform/landscape position and soil properties that are relevant for PAWC and soil fertility with the soil-landscape mapping and relevant map unit descriptions providing necessary insights.

The smallest mapping units of the three soil-landscape mapping systems used here usually still contain more than one landform element. As a consequence they often include multiple soil types, which are not mapped explicitly but need to be distinguished by the user on the basis of patterns of vegetation, landform and geology (Harris et al. 1999). The soil-landscape unit descriptions explain these patterns, but for untrained users such as farmers and advisors this is likely to still be a challenge. This highlights the need for extension work which could take the form of field days focussed on soil-landscape associations in a particular land system and how to recognise these in the field.

The advance of online tools such as the Soil and Landscape Grid of Australia, drawing on digital soil mapping and terrain analysis of the national digital elevation model (DEM) potentially provides another means to capture the within soil-landscape unit variation. Case study 3 suggests, however, that with version 1 of the Grid and 90 m pixels in that landscape we are currently pushing limits to distinguish within-landscape unit features. This is, however, a rapidly developing field. Terrain analysis has been shown to successfully disaggregate the Victorian Central Mallee and Hopetoun Land Systems (Hopley and Robinson 2010) into 10 landforms. It still needs to be confirmed whether the existing APSoil profiles in this region can be matched with these landforms or whether micro-variations, especially those relating to depth of subsoil constraints, will prove too subtle. Soil sensing tools like EM38 and gamma radiometrics may provide necessary complementary information.

A further challenge is that soil surveys are undertaken by jurisdictional agencies using slightly different methods for mapping, interpretation and presentation (e.g. with online systems). There have been significant advances in developing consistent methods through the Australian Collaborative Land Evaluation Program (http://www.clw.csiro.au/aclep/) and harmonisation of standards continues.

Soil-landscape models will be simpler for some landscapes than others. In particular where multiple, superimposed processes of soil formation have acted (e.g. in the older landscapes exposed to different climates over time), the resulting variation may not be easy to capture.

Conclusion

The introduction of spatially referenced, readily accessible online information provides an opportunity to make significant advances in the prediction of soil properties such as PAWC and subsoil constraints that impact strongly on crop agronomy and management. Making this information interpretable for farmers and advisors for application in their own paddocks will prove an exciting challenge for scientists.

Acknowledgments

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*Online soil-landscape information tools used:

NSW ESpade: http://www.environment.nsw.gov.au/eSpadeWebapp/

SA NatureMaps: http://www.naturemaps.sa.gov.au

Soil and Landscape Grid of Australia: http://www.clw.csiro.au/aclep/soilandlandscapegrid/index.htm

Farming practices at the landscape scale: a novel approach investigating rotations in the WA wheatbelt

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Abstract
There is a lack of regional scale information about how farming practices vary across agricultural landscapes. A novel, relatively cost-effective approach was used to characterise a 4000 km^2 broadacre region dominated by rainfed winter cereals and sheep systems in the central wheatbelt of Western Australia. Data was initially derived from existing maps, field observations and interviews with retired farmers to progressively differentiate landscape zones on the basis of similar geomorphology, history and land use.

Following this, soil and rotation information was collected from 35 farms that represented about half the farming businesses of the area. The duration and composition of 81 rotations typically implemented by farm managers were recorded. A map was developed of the study area that presents 3 relatively homogenous landscape zones, each composed of 3 broad soil types in varying proportions. Specialist croppers and mixed crop/sheep farmers conducted similar rotations on the sandiest of these zones. Differences were found on more loamy areas, on which mixed farmers replaced most of the break crops by pastures and tended to conduct shorter rotations than specialist croppers. In spite of the dominance of wheat and barley, the vast majority of farmers (91%) broke the cereal phase after 1, 2 or 3 years, most often with 1 year of canola, lupin, pasture, or chemical fallow. This type of landscape analysis could inform research and development by providing an original scale of investigation, thus complementing data sourced from governmental surveys and private consultants.

Key words
Landscape analysis, soils, rotations, broadacre farming systems, agrarian diagnostic, comparative agriculture.

Introduction
Numerous modelling studies have sought to identify economically optimal crop/pasture rotations and the impact of new technologies and enterprises. The research questions and assumptions about farms in a region, for which these studies are based upon, might be improved with more detailed information on the practices that dominate different areas of the agricultural landscape. There have been, however, few attempts at using farm management information to describe the utilisation of the landscape within given agricultural regions. At present, the main maps available at regional scales include crop capability and soil/landscape system surveys (e.g. van Gool et al. 2008; Sawkins 2010). There are currently no maps that show how the rotation strategies of farmers differ across the landscape. This study seeks to identify agricultural zones in the central wheatbelt of Western Australia and compare the rotations that currently exist on farms with different enterprise mixes. The preliminary results presented here are part of a larger project implementing a novel approach to study agricultural systems in Australia, using the concepts and methods of comparative agriculture (Cochet 2015; Hervieu 2012).

Materials and methods
The 4000 km^2 area studied is bounded by the towns of Cunderdin and Trayning (117°28'E, 31°23'S). Broadacre winter cereals and sheep systems dominate in this Mediterranean type of climate (~300mm/year). An agrarian diagnostic was conducted, which is an iterative procedure to study agricultural systems at regional scales (Barral et al. 2012). Only aspects relevant to the characterisation of the landscape are presented in this paper.

The procedure started by identifying relatively homogenous zones in the landscape. The criteria by which these zones were contrasted were not pre-defined, but emerged during the analysis. First, information was inferred from satellite imagery and existing maps of the local geology, topography, soils, climate, vegetation, infrastructure and administrative divisions. This information was then compared with field observations, focusing on geomorphological elements (e.g. relief, soil profiles) and land use (e.g. enterprises, paddocks shape and size, dams and ridges, etc.). The detail of the draft map produced was improved during interviews with retired farmers who could provide spatial and historical information.

This preliminary characterisation of the landscape was used to build guidelines for the second phase of the investigation, during which current farmers were interviewed. After drawing the farm boundaries, managers were asked whether they distinguished different areas and whether these were managed differently. Typical rotations for each of these areas were recorded, as well as any additional information volunteered by the farmer to further contextualise answers.

Respondents were recruited directly door-to-door, after being identified from previous participants or while driving in the study area. At first, respondents were selected at random within each landscape zone. Then, a purposive sampling technique was applied in order to represent all types of production systems present in the study area. Interviews were always conducted face-to-face, and mostly one-on-one to avoid group bias and ensure confidentiality.

Results

Following 3 weeks of field observations, a total of 54 interviews were conducted between June-August 2014 with a response rate of 96%.

Soil types

The first 17 interviews with retired farmers yielded 6 arable soils types generally named after distinctive vegetation or texture, e.g."tamma sandplains" or "salmon gum country". Later interviews with active farmers revealed some of these soils to cover only small areas or to be managed in the same way. As a result, 3 main soil types simply labelled "light", "medium" and "heavy" were finally distinguished, in spite of the heterogeneity of their physical properties.

Rotations

The current managers of 35 farming businesses where interviewed in detail, representing about half the farms of the study area. Of those, 46% were cropping specialists and 54% were mixed crop/sheep farmers. Average farm size was 5 300 ha, ranging from 780 ha to 16 500 ha (90% between 1 300 - 12 000 ha). Most managers (86%) characterised more than one soil type. Among them, 83% managed at least two soil types differently by conducting different rotations. A total of 81 rotations were recorded. Each was characterised by a typical pattern, even those qualified by farmers as 'flexible' rotations. This typical patterns allowed approximating the duration and composition of the rotations (Figure 1).

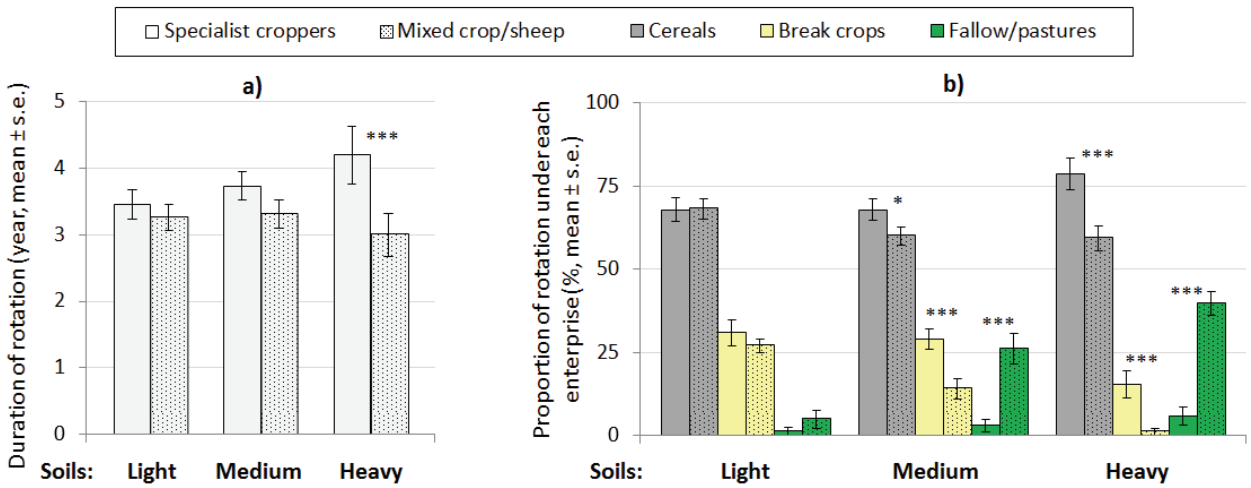

Figure 1. Duration and composition of rotations conducted in the central wheatbelt of WA. Participating farming businesses: 35, total number of typical rotations identified: 81. Each rotation counted once irrespective of the area sown. Unpaired standard t-test between farm types: * p<0.1, ** p<0.05, *** p<0.01

Wheat was by far the dominant enterprise in rotations for both farm types on all soil types. On average, rotations lasted 3.5 years, most of them (88%) not exceeding 4 years. Overall, the rotations were composed on average of 65% cereals, 20% break crops and 15% pastures/fallows. No permanent pasture was encountered on arable land, with pasture phases rarely lasting more than a year. Similarly, only two continuous cereal rotation situations were found, with the vast majority (91%) broken with other enterprises after 1, 2 or 3 years of wheat and/or barley. These other enterprises included canola, lupin, volunteer pastures, clover pastures and chemical fallows, and occasionally oaten hay and field peas.

Light soils were managed remarkably similarly by all farmers, with 2 or 3 cereals followed by a break crop. Differences appeared on the other soil types, on which mixed farmers replaced some of the break crops by pastures. Furthermore, mixed farmers conducted significantly shorter rotations on heavy soils compared to cropping specialists, with pastures replacing not only break enterprises but part of the cereal phase as well.

Landscape zones

Three main zones were distinguished (Figure 2), each composed of different proportions of the 3 broad soil types described before. Additionally, the zones featured different histories (settlement, clearing, ameliorants, enterprises etc.) and overall agricultural use (greater occurrence of pastures in valley floors and hilly sandplains).

Dominant broad soil types on farm 90% arable on average (approx. elevation a.s.l.)	**Light** ="Tamma country" Deep sands, gravelly sands, sands over clays or gravels (250 – 300m)	**Medium** ="Mix" & "jam country" Similar to Light soils, more shallow loams and rocky areas, steeper relief (250 – 350m)	**Heavy** ="Timber country" Loamy clays and sands, clays, saline areas (200 – 250m)
Average rotations			
Specialist croppers (40% of area)	**CC(C)B**	**CC(C)B(B)**	**CCC(C)B**
Mixed crop/sheep (60% of area)		**CC(B)P**	**CCP**
Zones localisation & composition			
Undulating sandplains (50% of area)	40 %	50 %	10 %
Hilly sandplains (25% of area)	30 %	60 %	10 %
Valley floors (25% of area)	10 %	40 %	50 %

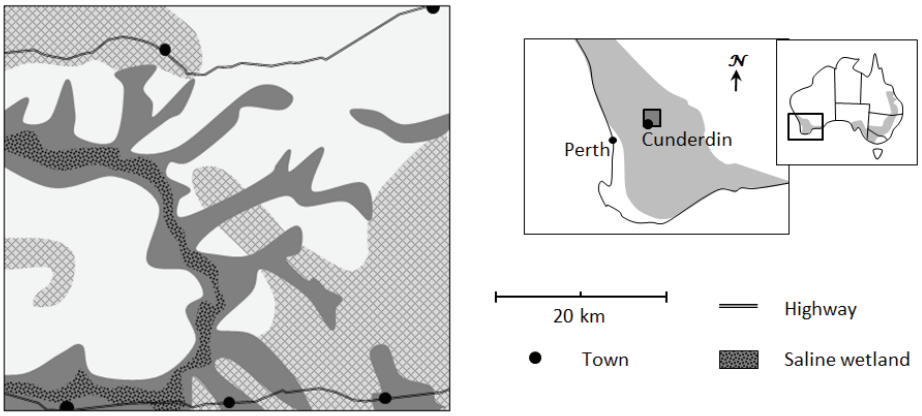

Figure 2. Landscape characterisation in the centre of the WA wheatbelt.
Sources: direct field observations, farmer interviews, published maps. Percentages are approximate. Rotations: C=Cereals (wheat, barley), B=Break crops (canola, lupin), P=Pastures (mainly volunteers, some sown). For instance, CC(C)B is equivalent to "2-3 cereals followed by a break crop", with cereals sown 2.5 years out of 3.5 and thus representing about 70% of the area under that rotation. Other enterprises such as chemical fallows and field peas were encountered but remained anecdotal.

Discussion

3 landscape zones, 3 broad soil types, distinct rotational practices

As can be expected, the 3 landscape zones identified closely match the landscape systems of existing maps (Sawkins 2010), although differences in definitions and boundaries can be noted due to the inclusion of farm management criteria. Similarly, the 6 soil types initially identified proved very comparable to the 8 land management units generally distinguished when modelling a typical farm in the WA central wheatbelt (e.g. Robertson et al. 2010). However, only 3 broad soil types were retained to analyse rotations, perhaps signalling a simplification of the landscape in terms of management practices.

This study also showed that continuous pasture and cereals are not representative practices in this area of the WA wheatbelt. Correspondingly, in spite of the low importance of break crops compared to cereals at the farm level (evaluated at 5-15% of farm area a decade ago by Robertson et al. 2010), their indispensable

role was confirmed with a vast majority of farmers including them in nearly all their rotations. The notable exception was mixed farmers using pastures on the heaviest soils instead (22% of all rotations).

Value for research and development
Contrasting distinct agricultural zones using the iterative methodology of an agrarian diagnostic was useful to demonstrate variations in farming practices across an agricultural landscape, in this case the duration and relative importance of enterprises in rotations. This information could help explain regional variations in farming performances, serve as baseline for crop sequence experiments (Seymour et al. 2012), or estimate areas for potential practice change (e.g. using Figure 2, heavy soils where rotations may be modified with suitable enterprises represent 20% of the area). Typical rotations associated with further farm information such as farm size could also contribute to calibrate typical farming systems, for use in benchmarking and modelling.

Evidently, farm-level considerations and fluctuations in weather and commodities prices are likely to modify the relative proportion of enterprises. Nevertheless, this study provides a rare picture of current practices, with previous landscape analysis by Galloway (2004) indicating that results are likely to have relevance for an area at least 3 times as large as the study area (Mortlock agricultural sub-region). Consequently, meaningful landscape divisions can be made following this approach that could complement the standard climatic partitions of the wheatbelt (e.g. Brown 1994).

Detailed practice information
Lastly, it should be highlighted that this study was able to detect management differences across farm types in spite of the over-dominance of cereals. This is noteworthy as few alternatives to private consultant databases are available that detail farmer practices at this scale, and that the costs of this research were relatively low. Cost-effectiveness was achieved by progressively prioritising the information to be collected, and by carefully defining "broad" soil types and "typical" rotations.

Conclusion
These preliminary results showed that different parts of the studied landscape are managed differently, with rotations of varying duration and composition. However, different types of farming did not necessarily result in different practices everywhere (case of the light soils). This is relatively counter-intuitive and demonstrates the value of the investigation, as distinguishing between specialists and mixed farmers is thus not necessary for all soil types when investigating rotations.

More generally, the study demonstrated that this novel type of approach at the landscape scale could complement farm-level studies, and contribute meaningful divisions of relatively large agricultural landscapes.

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Soil is the mirror of landscapes: Reflections on the legacy and future of soil knowledge management for sustainable farming

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Abstract
In 1898 V. V. Dokuchaev said "Soil is the mirror of landscapes". In 2015, International Year of Soils it is timely to for us to pause and reflect on what 20 years' of working closely with land managers, students and soil scientists in soil education and extension has taught us about changing soil knowledge needs for land management principally at the farm to regional scale. Our overall aim is to examine the set of challenges or opportunities that a legacy provides to future soil knowledge management in the hope that those working in agriculture and natural resource management are informed, equipped and connected to their landscape in order to manage their soil resource into the future. The future relevance of soil education and extension to practitioners is learning from the legacy and acknowledging existing logistical and intellectual challenges. We will outline those challenges and reflect on whether we are capable of making the cultural shift in how we approach soil education and extension to embrace and blend new technologies with some of the "tried and tested" stalwarts of education and extension.

Key words
Soil education, soil extension, online, linear approach, communities of practice

The Issue: soil knowledge production and communication
Australia faces a number of logistical and capacity challenges in connecting land managers of its soils resource with soil science educators and extension practitioners. Those being educated in soils through higher education find themselves distant from farming landscapes, and consequently students are less exposed to the real world complexity of soils, as most universities reside along the coast in urban areas. Soil credentials may be gained, but hands-on field experience is limited, impacting on critical problem-solving skills needed for identification and remedying soil management issues, and therefore diminishing the ability of graduates to work effectively in regional and remote areas in soil-related jobs. Improving information literacy of graduates, especially where most research information is internet sourced, teaches skills in accessing and interrogating soil information at appropriate scales, which enables the recognition of what is the most relevant information for the scale of application (Haigh, 2006). Another hurdle to improved information flow (both in relevance and accuracy), is archiving soil information (not updated, due to program completion or funding cuts e.g. Land and Water Australia (1990-2009) at: http://lwa.gov.au/ and National Land and Water Resources Audit (1997-2008) at: http://lwa.gov.au/programs/national-land-and-water-resources-audit) or de-contextualising information, stripping it back to basics so it's only presented at regional or state scale, rather than at a useful scale for a land manager (Australian Bureau of Statistics data on Land Management and Farming in Australia (2014) at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/4627.0). For soils in particular, access to information of local relevance is further compounded by a disconnect between data sets and user location. Sampling effort is greater in coastal zones than inland where most of the farming community reside resulting in patchiness in data coverage and quality (CoA, 2014). In addition, poor internet connectivity particularly in rural and regional areas hampers access to online sources of information.

A capacity constraint in both the university and soils' technical specialist sector regarding soils' education/extension is the aging nature of the workforce, which also parallels the aging workforce in agriculture (CoA 2014). The loss of experiential and expertise knowledge with an aging workforce is a dilemma that could be addressed in some way with succession planning. However, succession planning is not an area that universities, government departments or farmers are noted for implementing well. Alternately using existing or developing knowledge networks (such as those that currently exist in NSW with retired soil scientists) or nation-wide data bases may in some way address these concerns. Where the next generation of knowledge holders and generators come from is not clear. As Hunt et al., (2014) identify the positive feedback loop whereby reduced government involvement has led to a decline in employment opportunities and thus fewer graduates and undergraduates studying the field which further reduces the number of skilled professionals and tertiary resources for this area of study.

The intellectual challenge in soil education and extension is presenting soil in a holistic and integrated way that does not reduce it to component elements such as soil physics, soil chemistry, soil fertility and soil biology or as Bouma (2010) put it: "combating current atomization of subdisciplines". The silo approach to soil education, research and extension belies the complex interactive nature of its workings and tries to simplify the soil biosphere by detaching it from the landscape from which it was formed, and fails to acknowledge the multi-functionality of soil in the environment. The separation of soil from a specific context within the landscape increases the difficulty in developing, researching and implementing viable solutions to the soil issues facing Australia (Hunt et al., 2014).

Training the new generation of soils' champions

In education, exposure to soil science is becoming restricted to a foundation unit early in a degree program, more as part of a multi-disciplinary university degree such as agriculture or environmental science, and less often as a series of units for a major specifically in soil science (Hartemink et al., 2014). Increasingly undergraduate students are focusing on 3 year Bachelor degrees with few options for elective units, which leave little room for "specialisation" in the discipline of soil science. These changes could be viewed as a positive shift to integrate soil education with other disciplines and appreciating that soil is part of a social ecological system that also includes a human dimension: land managers (Hartemink et al., 2014). Alternately one could also argue that the education of undergraduates in soil science is limited and that science degrees can be undertaken and gain only a superficial understanding of soil science knowledge. In contrast to this there is an increasing interest amongst land managers in approaches that recognise the complexity of the soil system and the difficulty in applying "one-size-fits-all" solutions. Suggesting a desire (and we would add, need) to understand the 'why' as well as the 'what' of new practices for soil management, as understanding why something works will only assist the land manager in its adoption. Soils-focused groups such as Soils for Life (found at: http://www.soilsforlife.org.au/about.html) and SoilCare (NSW) (found at: http://www.soilcare.org/) exist because of farmer interest in managing soils better and a desire to share experiences and knowledge. These groups have developed largely outside the major R, D and E structures, isolated from existing knowledge sources with few communication links to recognised R and D. The risk is that research outcomes do not always inform these groups and their management choices, at the same time current R and D cannot learn from the land managers' experiences

There is a reticence for university educators or those working in extension to move beyond their own teacher-centred, educational experience, and the passive linear delivery of material, devoid of context and immediacy. With this model students or landholders have little opportunity to interact or interrogate content, to be more interactive and to engage in experiential learning with opportunities to build communities of practice (Lobry de Bruyn et al., 2014). Importantly moving to a student-centred learning focus will establish life-long learning skills for those who participate, and will pay dividends in any future interactions with others involved in soil management (Field et al., 2011). Achieving this goal requires a shift in mind-set from one where current soil specialists are the purveyors of all knowledge to one of facilitating knowledge enquiry with their audience (Field et al., 2011). This change in teaching paradigm and practice is difficult for some researchers, academics and extension agents to accept, since many have not sought to undertake any teacher training or gain educational qualifications. The lack of scholarship in teaching and learning is because it is not given the same value as core science nor is it valued for promotion or progression. Understanding that groups can be part of a (participatory) research model, engaged in providing long term support and on the ground information to foster the development of workable solutions and behaviour change. The most successful behaviour change projects occur when farming systems groups and research providers develop and implement projects together and support each other over the longer term (Gianetti and Carmody, 2007). Also, for successful collaboration between researchers and practitioners there also needs to be genuine interest in and respect for each other's perspectives and knowledge.

Facilitating the flow of two-way knowledge exchange

Arguably much beneficial soil knowledge is "produced", though frequently scientists lament the lack of interest in or adoption of their findings by land managers (Bouma, 2010). Is this a result a consequence of not involving those who will benefit from the research at an earlier point (Knickel et al., 2009; Lobry de Bruyn and Abbey 1999)? There is greater emphasis on satisfying research funders by creating information outputs with far less time to demonstrate practice change realities to ensure new soil information is incorporated into day-to-day farming practice (Bouma, 2010). Aside from conservation farming in Australia, which has been widely adopted, there are few indications that simply providing soil information drives better practice (Llewellyn et al., 2012). A recent stocktake of current investment in Australian national soil R, D & E staff category re-enforced the limited investment in soil knowledge exchange showing 12.5% in extension and 6% in teaching, with the majority of staff in research (39%), and postgraduate training (26%) (DAFF, 2011). Again the adherence to a linear

approach rather than a participatory one combining scientific expertise and experiential knowledge, inclusive of all stakeholders and encompassing the practice of life-long learning is a missed opportunity (Moschitz and Home 2014). Making the connection between scientists and land managers requires greater thought put into developing social networks. Strong ties (friends and family) affirm what is known and weak ties (farmers with researchers and extension providers) are used to acquire new information (Gianetti and Camondy 2007, Thuo et al., 2014). Familiar traditional extension activities are still major information sources for agricultural land managers with field days and training courses the key sources of information on sustainable land management practices (Kancans et al., 2014). However, proportionally, these activities do not lead to as much demonstrable practice change as direct involvement in on-farm research trial work or involvement in best practice farmer groups (Kilpatrick and Johns 2003, Kancans et al., 2014).

It is our contention that we need to reframe how soil is communicated to an audience both in content and process, and engage more in communities of practice in order to avoid a further separation of researchers and practitioners (Bouma, 2010). This re-positioning of soil education and extension encompasses a multi-disciplinary team that seeks to build networks with land managers who bring along their own experiential knowledge of soil (Lobry de Bruyn and Abbey, 1999). A process of engaging farmers that prompts them to become their own researchers, observers and decisions makers (action research model) is far more beneficial than a technology transfer model (a linear approach) (Roling 1995). That is, an approach that promotes their own discovery is more likely to encourage farmers to become further interested in their soil and thus actively manage it in a more sustainable way (Jenkins, 2006). Provision for non-linear networks in extension such as supporting farmer-to-farmer learning seems to have dwindled as evidenced by the withdrawal of publicly funded extension services (Hunt et al., 2104) and a reduction in funding to support programs such as Landcare, mirrored by a noticeable decline in farmers involved in Landcare with membership slipping to just over 20% of Australian farmers (ABS 2013). These reductions in capacity greatly impact on landholder engagement, further distancing the researchers from intended users/collaborators (Campbell, 2008). The alternative to closer engagement is a national approach of disbursing messages and research knowledge directly to industry bodies or private advisors due in part to a deliberate decoupling of research and extension services (Hunt et al., 2014). This approach has been critiqued by Wong and Edis (2013) as a "piece-meal approach" which they felt missed the "bigger picture" due to consultants being hired to address specific problems or tasks. In fact, Hunt et al., (2014) state plainly that the assumption that the "private sector would sufficiently fill the gap left by the public sector exit….has proven to be over-optimistic."

Using new tools to support tried and tested models

Online delivery of soil information in Australia, hopes to overcome the tyranny of distance and fill a void as the number of soil specialists decline across Australia. Harnessing it to meet the growth in university soil education and extension delivery of courses and material is one solution to connecting a dispersed geographical soil community. Ease of internet connectivity and creating an online community where people feel connected to each other and learning materials or experiences is still to be resolved. How we blend the virtual world with the sensual world of soil, and at the same time place the audience at the centre of their learning has yet to be fully tested. Digital technology makes visual media affordable and easily distributed, and social media platforms such as Twitter are increasingly used by organisations to promote their activities (e.g. FAOKnowledge found at: https://twitter.com/FAOKnowledge). They are particularly useful for awareness-raising of issues, to catch viewer attention and to stimulate interest, but online media are less powerful for practice change and discussion. Recognition needs to be given to the approach or pedagogy of learning that will positively shape and influence our interactions with practitioners in the field or workshop (Field et al., 2011). If we believe in the adage: "Tell me and I'll forget. Show me and I'll remember. Involve me and I'll understand", then soil education and extension needs to be student-centred and have actual field experiences and group work, hence combining online with face-to-face interaction (Hartemink et al., 2014). E-extension (for example go to: http://www.extensionaus.com.au/) is being trialled in various topic areas such as crop nutrition and plant protection in Australia with some success in providing timely useful information to the intended audience (pers comm Luke Beange). It could be argued, that if online portals are not implemented cleverly, with high quality content and sufficient space and time for participant contribution, they advance little from the linear model of information transfer. The gap between those that are directly involved in field research trials with internet competence and those who are not will widen. It is important to note that an e-extension model does not, as some may hope, reduce the need for skilled professionals or face to face events. A dispersed community of practice requires a great deal more work to foster the relationships and trust required for knowledge sharing than groups that meet face-to-face (Lobry de Bruyn, 2004). There are a few government sanctioned communities of practice but as noted earlier effort in facilitating and sustaining such a community requires a dedicated driver(s).

Conclusion

The central premise of this paper is that we have yet to decouple our vision for soil education and extension from the linear positivist paradigm and move to an inclusive non-linear philosophy that encompasses those with expertise and those with experience on soil knowledge and practice. It seems to us that over the past 20 years the call for more non-linear approaches have largely been rhetorical, with few demonstrable widely-accepted alternatives put into practice. The repercussions of adhering to the linear view ripples through many of the points we have discussed in terms of knowledge partnerships and the way we view learning and knowledge production and its subsequent communication to those who need to use it. A multi-dimensional approach to soil education and extension is needed where there is a mix of familiar models with the new, creating a learning environment that facilitates change. New technologies are proving useful for providing information where geographically dispersed populations are remote from service providers or education facilities but they cannot totally replace the face to face required to gain more complex skills in soil nor the discussion required to develop new and innovative solutions to the complex problems that exist at the landscape scale. We must remember that information provision is not the same as gaining of knowledge, and does not necessarily lead to practice change. We as soil educators and extension agents must also become better at completing the learning cycle, using critical evaluation and reflection to assist us in determining what is effective and how the information and knowledge generated is used to manage our soil better (Lobry de Bruyn et al., 2014).

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Smallholder farmer innovation. 1. Replacing transplanted rice monoculture with direct seeded rice based cropping systems.

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Abstract
We describe our experience working with smallholder farmers on the East India Plateau to develop more diverse and intensive farming systems. What at first appears as a relatively small change in rice establishment agronomy, turns out to be a key to unlocking a range of development opportunities including increasing crop productivity, farm profitability, and climate resilience, enhanced human nutrition, and empowerment of women.

The approach is illustrated with a local farmer innovation in rice establishment systems. Transplanted rice is very risky in this environment due to lack of irrigation, erratic rainfall, soil type and undulating landscape. Farmers have developed a direct seeded rice system that is different, perhaps unique, from previous direct seeded systems. Here the soil remains unpuddled, seed and fertiliser are manually sown in lines, and weed control is achieved with small manually operated implements.

In addition to improved yield stability, early sowing and early harvesting, and using residual soil water for a second crop, the new system releases women from labour drudgery (no transplanting or hand weeding), is more climate resilient (avoids rice crop failure due to lack of ponding needed for transplanting), and is nutrition sensitive (harvesting the rice crop earlier in the 'hunger window', and enabling a second oilseed, pulse or vegetable crop). The new system is popular with farmers and adoption is expanding rapidly.

Key words
Sustainable intensification, crop diversification, participatory action research, climate resilience, nutrition sensitive, gender friendly.

Introduction

Severe poverty and malnutrition are endemic on the East India Plateau, especially in rural communities where subsistence agriculture is the primary livelihood. Here, cropping systems are dominated by rice monoculture and traditionally rice is transplanted to coincide with the arrival of the monsoon in June and harvested towards the end of the monsoon in November. However, early monsoon rainfall is unreliable, compromising opportunities for ponding to transplant rice in this environment (Cornish et al, 2015). The undulating topography of the plateau combined with coarse textured soils, and variable rainfall thus results in either failure to transplant or transplanting very late. Failure of the rice crop, and/or low rice yield due to on or late transplanting, has dire consequences for food security, resulting in distressed migration among other impacts.

Against this background ACIAR is supporting an agricultural research for development project that is delivering significant agricultural and livelihood benefits in largely Tribal communities. This paper focusses on research to develop a more reliable system of rice crop establishment based on direct seeding rather than transplanting. The paper describes the traditional farmer practice and the direct seeded intervention, the role of farmers in developing the new system, the grain yield reliability of the new system, and some of the wider development implications.

Materials and Methods

The research is located on the East India Plateau spanning the states of Jharkhand and West Bengal. Average annual rainfall is around 1,200 mm, falling mainly from June to October in a typical monsoon pattern. Agriculture is mainly rainfed with little development of surface or groundwater resources for irrigation. A typical calendar of management events for transplanted rice is provided in Table 1. In response to the high risk of transplanted rice failing, we developed a direct seeded rice establishment system in partnership with

local farmers (Table 1). The salient features of this locally developed aerobic direct seeded rice (aDSR) system include; the soil is not puddled, seed and fertiliser are sown directly by hand in rows into moist (not flooded) soil, paddy ponding is facultative as determined by rainfall distribution, inter-row weeding is achieved with manually operated small weeders (wheel-hoe when not ponded, *cono* weeder when ponded). Aerobic DSR is harvested earlier than tradtional transplanted rice. The experimental design is a paired comparison (TR vs aDSR) in farmer fields under farmer management. The research is located in three villages (Bhubhui, Talaboru, Churinsara) and conducted over three years (2013, 2014, 2015). Data is collected on climate, crop management practice, crop inputs, labour inputs, soil fertility, soil water at rice harvest and *rabi* crop harvest, crop phenology, crop growth and grain yield. Only the yield data for 2014 is presented here. Farmers participate in identifying the research question, imposing and managing treatments, data collection, and disseminating research results (Pandey, et al, 2015).

Table 1. Comparison of traditional Transplanted Rice (TR) with locally developed aerobic Direct Seeded Rice (aDSR).

Indicative timing	Traditional Transplanted Rice (TR)	Aerobic Direct Seeded Rice (aDSR)
Feb-March	Fallow	Harvest preceding *rabi* crop (e.g. chickpea or Mustard).
March-May	Fallow	Fallow
May	Plough (traditional wooden plough behind buffalo) if rain	Plough (traditional wooden plough behind buffalo) if rain.
June 1-15	Possibly second plough, then harrow to level out seedbed. Prepare nursery, plough and spread manure.	Possibly second plough.
June 15-20	Optimum time for sowing nursery. If rain, plough main field.	Optimum sowing time, depends on receiving some rain. Levelling, and line marking (seeding furrows). Seed prep, sort seed, 5% brine water, rinse with fresh, treat with fungicide. Lay out lines for sowing by hand, 25cm row space, two seeds every 10 cm, or use 5-row '*letho*' tillage tool, apply fertiliser; 70 kg N/ha, 42 kg P/ha, 30 kg K/ha.
early July	Plough 2-3 times. Puddle, dependent on ponding. Transplant if ponding permits: random spacing, >5 seedlings, 20+ days old.	First weeding using mechanical wheel hoe, *cono* weeder if wet.
early-mid July	Ponding.	No ponding at this time to avoid damage to germinating seeds and young seedlings.
late July		After weeding apply 1/3 to 1/2 of recommended rate of urea.
July-August	Early tillering. First hand weeding.	Second weeding with *cono* weeder. Once seedlings 20cm high allow opportunistic ponding.
late August	Second weeding (hand), depending on time of transplanting. Broadcast urea after weeding.	Final urea application to coincide with maximum tiller number (up to 40).
late Sep to last Oct		Harvest time depends on maturity of rice cultivar (Early 90 day, Mid 120 day).
October		Sow *rabi* crop to utilise residual soil water (relay crop option).
November	Harvest is typically later due to longer duration variety (120 + days) and later transplanting.	Growth of *rabi* crop.
Dec-Jan	Fallow	Growth of *rabi* crop.

The evolution of rice establishment systems on the East India Plateau (EIP) is described in Figure 1. The traditional practice of transplanted rice (TR) requires fields to be puddled and young rice seedlings are

manually transplanted into ponded paddy fields by women. Weed control is achieved by hand weeding, again a task reserved for women. In some communities, when the monsoon arrives late, or if labour is scarce, seed is broadcast with fertiliser onto cultivated soil (BR). This low input system usually results in poor weed control and low yields. A System of Rice Intensification (SRI, Uphoff et al, 2011) with higher plant density, better weed control, and taiklored fertiliser rates, etc. usually results in higher yields, but still relies on transplanting and so is exposed to the risk of late or no ponding and serious crop failure. In partnership with farmers we have developed a locally relevant direct seeding rice establishment system (aDSR). The aDSR and TR systems are described in more detail in Table 1, but it is important to note that aDSR was developed with local farmer input and does not require puddling or ponding, although opportunistic ponding can still occur in bunded fields if rainfall permits. Although not currently practiced widely on the EIP, Conservation Agriculture is included in Figure 1 to contrast with aDSR. The CA system is a product of western industrialised agriculture relying on specialised machinery and herbicides. While CA can be adapted to smallholder conditions, the technology represents too large a leap in technology and investment for resource poor farmers in the region.

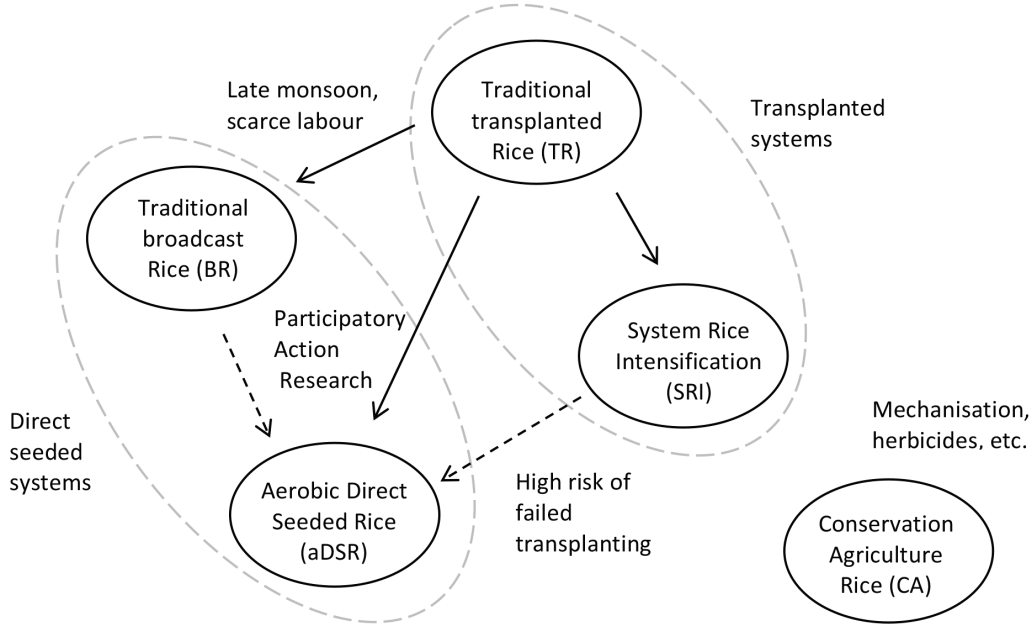

Figure 1. A typology of rice establishment systems on the East India Plateau.

Results

In addition to being a significant development in rice establishment system, aDSR also is a key to further intensification and diversification of rice-based cropping systems in the region. Because aDSR does not require ponding for transplanting, rice can be sown earlie, and combined with a short duration rice variety (90 to 110 days) this results in rice harvest in mid-October, approximately four weeks earlier than for TR. Earlier rice harvest is the key to early sowing of a second (*rabi*) crop of mustard, chickpea, or wheat, etc., thus making use of residual soil water after rice harvest and improving food security.

Results from the 2014 monsoon (*kharif*) season illustrates the advantage of aDSR over TR when the monsoon arrives late (Figure 2). Under farmer managed, on-farm conditions, 23 out of 43 TR crops failed due toan inability to transplant for lack of ponding opportunity. By contrast, only 5 aDSR crops failed. The 2014 result highlights the relative climate resilience of aDSR since while transplanted rice fails due to lack of ponding, there is still ample soil water to grow a direct seeded rice crop. This failure of TR despite adequate soil water has been described as a '*paddy drought*'. The 2014 result also highlights the opportunity foraDSR to increase food security otherwise resulting from crop failure. In addition, aDSR yields were similar to TR yields even when growing conditions were suitable for TR (Figure 2).

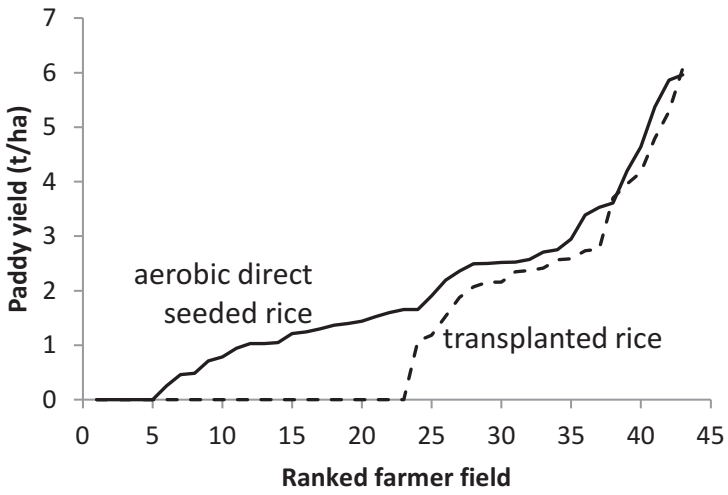

Figure 2. Comparison of paddy yield for Transplanted Rice and aerobic Direct Seeded Rice) from three villages in Jharkhand (Bhubhui, Talaboru) and West Bengal (Churinsara) for the 2014 *kharif*. Note 23 traditional crops failed due to inability to transplant , whereas only five direct seeded crops failed.

Discussion and Conclusions

A key advantage of aDSR is that rice can be established earlier,with much less rainfall, even in years when the monsoon arrives late. Also, the probability of crop failure is greatly reduced, so aDSR can be described as climate resilient. A second key advantage of aDSR is that the labour requirement is much less than required for TR. Moreover the labour saved, transplanting and hand weeding, traditionally reserved for women, is gender friendly in that it releases women from drudgery, allowing them to invest their time in more profitable enterprises such as vegetable cash crops. A third advantage of aDSR is that it facilitates a nutrition dense *rabi crop* (vegetables, chickpea, mustard) and since it can be harvested up to four weeks earlier than TR, provides much needed calories earlier in the traditional lean season.

Farmers are adopting and adapting the aDSR system for the advantages outlined above. Independent farmer innovations include intercropping with black gram (*Vigna mungo*), relay cropping with chickpea (*Cicer arietinum*) and extending direct seeding principles to other crops such as mustard. In addition to developing the system locally, farmers have been engaged in the on-farm research, and in the dissemination and diffusion of the intervention. Demand for simple manual implements required for aDSR is outstripping local supply. While the participation of farmers in the research and innovation has been the key to a successful intervention and scaling out, our process of deep farmer engagement has an even more profound legacy. Participating women farmers demonstrate empowerment and enhanced capacity for independent innovation. The transformative learning outcomes associated with our process of engagement are explored in Pandey, et al (2015).

Acknowledgements

The time, knowledge and expertise of participating farmers is acknowledged and admired. The financial support of ACIAR project LWR/2010/082, *Improving livelihoods with innovative cropping systems on the East India Plateau* is gratefully acknowledged.

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Combining field trials and crop modelling of dry direct seeded rice to reduce production risks in Lao PDR under current and future climates

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Abstract
Rice in lowland Lao PDR is produced under rainfed conditions with little or no access to supplementary irrigation. Farmers operate on small scales with the primary aim of achieving food security. The traditional establishment practice of puddled transplanted rice (PTR) exposes farmers to climate risks at both the commencement and conclusion of the wet season. Additionally, PTR has high labour requirements at the time of transplanting. Over four years, a research team from CSIRO (Australia), the National Agriculture and Forestry Research Institute (NAFRI, Lao PDR) and the Provincial Agriculture and Forestry Office Savannakhet (PAFO, Lao PDR) has worked with farmers in Savannakhet Province to explore on farms the potential benefits of dry direct seeding rice (DSR). DSR enables farmers to sow, and to grow to maturity, a comparably-yielding rice crop with less water than is needed for PTR. As the crop can be sown earlier in the season (without having to wait for the presence of ponded water) risks of terminal drought stress are also reduced. Provided that weeds are well managed the labour demand is significantly reduced relative to PTR, thus decreasing farmers' production costs. Crop system modelling using APSIM has demonstrated the advantages of DSR apply over the longer term, for both current and future climates. Participatory engagement with farmers and extension agencies indicates many farmers' strong interest in DSR and determination to continue to engage in mechanised rice establishment to decrease their production costs while maintaining or improving food security.

Keywords
Dry direct seeding, crop modelling, climate change, rainfed rice

Introduction

Rice is the staple food crop in Lao PDR. In lowland areas of southern Lao PDR it is predominantly produced in the wet season (May to October), with very little, if any, access to supplementary irrigation. Wet season rainfall is highly variable temporally (both within a wet season and from year to year) and spatially (Basnayake et al., 2006). The traditional method of crop establishment, transplanting (PTR), exposes farmers to climate risks at both the commencement (highly variable rains impede successful nursery propagation and transplanting) and conclusion (terminal drought stress) of the wet season. Additionally, PTR has high labour requirements at the time of transplanting.

Most farmers operate on small scales (0.5-2 ha) and are constrained by access to labour; in most households at least one member provides an off-farm income (Chialue et al., 2013). Accessing additional labour on-farm in times of high demand (e.g. at transplanting) either reduces the household's external earnings potential or requires expenditure to hire labour. Farmers are risk averse and keen to maintain sufficient yield for food security while reducing input costs: for most farmers the primary production goal is food security not a marketable rice surplus.

Dry direct seeded rice (DSR; Lantican et al., 1999) is an alternative establishment technique with potential benefits for farmers in rainfed lowland Lao PDR. A DSR crop can be sown early in the season, on limited pre-monsoon rainfall and can be grown to maturity on less water: there is no need for water to pond in paddies, as there is for traditionally established rice which requires standing water for transplanting. Sowing the rice crop earlier in the wet season reduces the risk of terminal drought stress; additionally plants establish

sooner, do not suffer transplant shock and are better positioned to resist short-term drought or flooding events. Where weeds are well managed the labour demand of a DSR crop is considerably lower than that of a PTR crop; farmers' production costs are consequently lowered, even allowing for additional expense incurred managing weeds.

Examining dry direct seeded rice establishment in rainfed lowland Lao PDR

Between 2011 and 2014 a research team from CSIRO, NAFRI and PAFO Savannakhet worked with farmers in Savannakhet Province to explore the potential benefits of mechanised establishment. The aims were to introduce farmers to the new establishment technique and to examine if DSR is suitable for use in lowland rainfed areas of Lao PDR. On-farm trials were established in 2011-2013 on up to 66 farms each year to expose as many farmers as possible to DSR, using Thai dry direct seeders. Training in the use of the seeders was provided to farmers and local extension staff by experts from World Vision Thailand; training in Good Agricultural Practices (GAP), including weed control via thorough land preparation and early manual weeding, was provided by NAFRI. In 2014 a locally modified seeder, which placed fertiliser with seed in the soil at sowing, was introduced following feedback from farmers. Testing on nine farms compared four treatments: 1) PTR+GAP; 2) DSR+GAP; 3) DSR with poor early weed control (resulting in a reduced yield and higher labour requirements for weeding during the season); and 4) DSR with a chemical herbicide.

Simple gross margins (GMs) were calculated to compare the potential economic differences between the treatments. As well, the labour required to produce each rice crop was examined relative to the yield obtained.

The APSIM cropping systems model (Holzworth et al., 2014) was used to extend results from on-farm field trials to compare PTR and DSR between 1971 and 2011 and for a future climate (locally relevant climate data were simulated using the GFDLCM 2.0 GCM as described by Kokic et al. (2011)) between 2021 and 2040. Initial field trial data, supplemented from the published literature, were used to parameterise and calibrate APSIM for Outhoumphone and Champhone districts. Subsequent field trial data were used to validate the model before it was used for scenario analysis.

Results and discussion

On-farm DSR testing and economic analysis

Table 1 shows average yields results from 2014, the labour requirements to achieve these yields and the calculated gross margins from the nine farms which participated in the on-farm testing. Comparable yields were achieved under Treatments 1 (PTR+GAP: 3.3t/ha); 2 (DSR+GAP: 3.3t/ha) and 4 (DSR+herbicide: 3.4t/ha), indicating that (relatively) high yields can be achieved under both PTR and DSR with or without the use of chemical herbicides, as long as weeds are well controlled (i.e. in contrast to Treatment 3, DSR+poor early weed control, which achieved an average yield of 2.9t/ha; or average yield from participating farmers' fields under traditional PTR which was 2.0t/ha in 2014). Farmers establishing a DSR crop can no longer rely on traditional practices, in particular the presence of standing water in paddies, to control weeds. However, farmers expressed a strong preference against chemical weed control because it increases input costs and negatively affects paddy biota (frogs, fish, snails, etc) which are important protein sources for farming households during the wet season. Many farmers reported that manual weeding was easier in the straight rows between plants in DSR paddies than between the less rigidly-placed plants in PTR paddies.

Farmers are attracted to DSR largely because of the potential overall savings with reduced labour requirements for crop establishment (these savings are achieved notwithstanding a higher labour budget for weed management): Table 1 illustrates that all DSR treatments required fewer person days per hectare (40 to 52) to produce a crop than were required in the PTR treatment (78). As rice is produced largely for domestic consumption in Lao PDR (primarily using unpaid household labour) the gross margin calculated for each treatment does not represent a cash gain or loss the household would incur: rather GMs are a tool used here to compare the value of establishment methods under different treatments. Table 1 shows that DSR with good weed control (Treatments 2 and 4) improves GM relative to PTR+GAP (Treatment 1). Where weeds are not well controlled early in the season (Treatment 3) subsequent high labour requirements and a yield penalty result in a GM lower than that of PTR+GAP.

Table 1: 2014 average yield and labour requirements, and gross margins under DSR and PTR treatments

Treatment	Yield (t/ha)	Labour (person days/ha)	Gross margin (LAK/ha)[1]
1: PTR+GAP	3.3	73	1,703,200
2: DSR+GAP	3.3	52	2,928,400
3: DSR+poor early weed control	2.9	68	1,409,000
4: DSR+herbicide	3.4	40	3,685,600

[1] 1 AUD is approximately 6375 LAK

Figure 1 illustrates the yield return on labour required to produce a rice crop: DSR+GAP results in 62.9kg/person day and is a more attractive option than PTR+GAP (45.6kg/person day), DSR+FP (43.3kg/person day) or DSR+herbicide (85.0kg/person day: this option is not attractive to Lao farmers because of the additional use of chemicals).

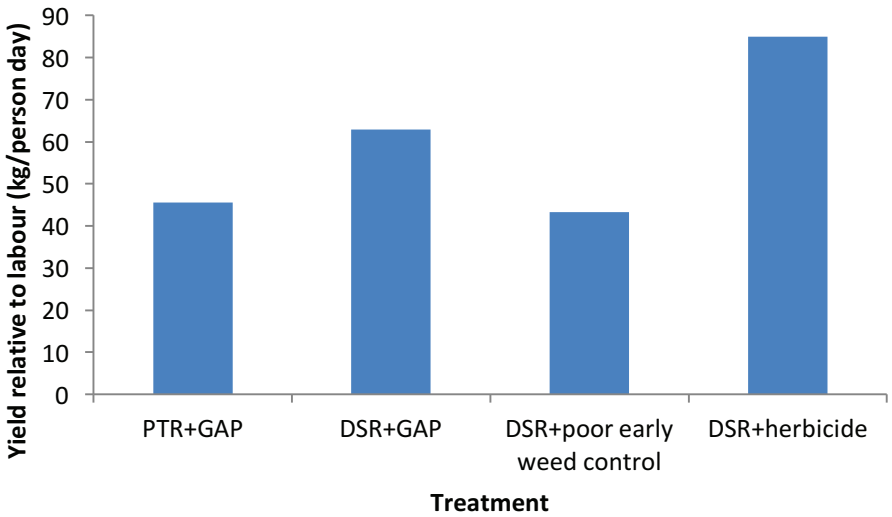

Figure 1: Yield relative to labour required to produce a rice crop (kg/person day)

Crop simulation modelling

Field trial data indicated comparable yield results between PTR and DSR for years in which the on-farm testing was run. A comparison using APSIM, in which weeds were assumed to be well controlled, suggests that in the longer term (i.e. over 40 years between 1971 and 2011) DSR is likely to perform better than PTR: the number of crop failures (i.e. 0t/ha yield) will reduce and average yields will increase from 3.3t/ha under PTR+GAP to 4.0t/ha under DSR+GAP (Figure 2).

Under a future climate, between 2021 and 2040, yields are likely to increase above present day long term estimates under both PTR+GAP (4.3t/ha) and DSR+GAP (4.5t/ha) (Figure 2). In both treatments crop failures are no longer simulated: these results are largely due to increases in rainfall during the wet season, in particular early in the wet season. In the best 30 per cent of years there will be little difference in crop yield between that achieved under DSR+GAP in the historical simulation and that achieved under either DSR+GAP or PTR+GAP in the 2021 to 2040 scenarios: in these years water stress does not impede crop growth; rather, greater yield production is inhibited by a lack of nitrogen.

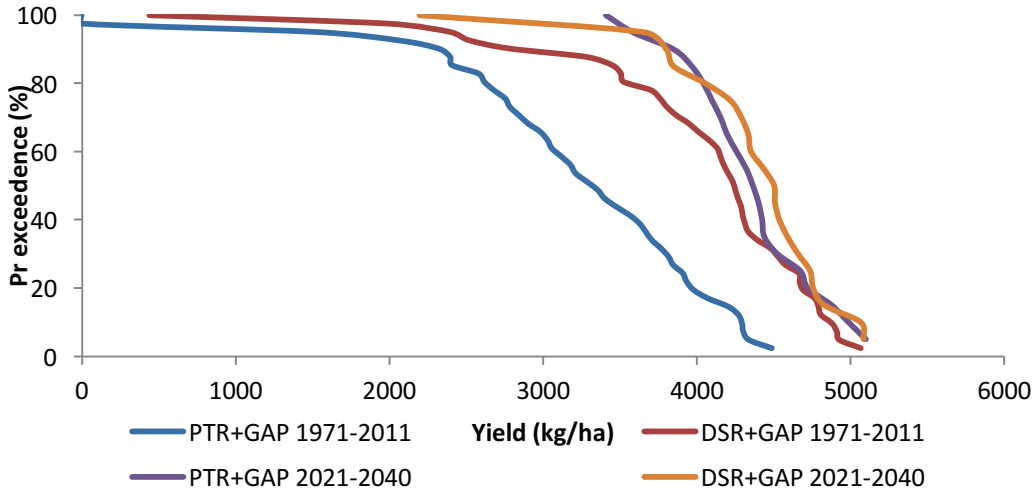

Figure 2: Probability of exceedence curves for yield (kg/ha) for PTR+GAP and DSR+GAP under present day (1971 to 2011) and future (2021-2040) climate data

Conclusion

On farm testing of DSR has demonstrated its potential for rice farmers in rainfed lowland Lao PDR. DSR enables farmers to sow, and to grow to maturity, a comparably-yielding rice crop with less water than is needed for PTR. Where weeds are well managed the labour demand is significantly reduced relative to PTR, thus decreasing farmers' production costs and enabling greater opportunities for off-farm income generation for the household. In the longer term under both current and future climates DSR remains an attractive option to maintain or increase yields and to reduce farmers' exposure to climate risks.

Throughout this research farmers have maintained a keen interest in DSR and, with assistance from local research and extension agencies, have expressed a determination to continue to engage in and experiment with dry direct seeded rice to decrease their production costs while maintaining or improving food security.

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Resilience of smallholder farmers in Cambodian lowland rice ecosystems in managing for future climate uncertainty

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Abstract
Rice production is the major source of food security for the Cambodian population and planted to 85 % of the country's arable land, of which 90% is rainfed lowland rice. Medium and late maturing varieties account for >70% of the rice planted during the summer monsoon. By 2050 climate change is predicted to reduce rainfed cultivation area by 20%. Adaptation strategies developed through collaborative research with farmers support the replacement of traditional low input systems with a 'response farming' approach for better temporal utilisation of available labour, land and water resources. Replacing a traditional transplanted crop with short duration varieties, more efficient establishment methods and better agronomic and fertiliser management that responds to timing, intensity and longevity of the monsoon has potential to mitigate effects of climate change. Using the APSIM model and a downscaled GCM baseline climate scenario production risk from an increase in temperature of 0.7-2.7 °C, an atmospheric CO_2 concentration of 509-638 ppm and variation in rainfall, for rainfed and irrigated systems to 2060 was evaluated. Simulated rice yields under higher CO_2 increased by 6.11% (380-480 ppm) and 4.13% (630-730 ppm) per 100 **µ**mol mol^{-1} while rice yields decreased by 4% per degree increase above baseline temperatures. Without irrigation or better utilisation of available water through use of short duration varieties, distribution and timing of rainfall has significant impacts on productivity. Simulations show that interventions are beneficial for managing risk from extremes of CO_2 and temperature on rice production to at least 2030.

Key words
Response farming

Introduction
Food security in the face of population growth, urban migration, loss of agricultural land and climate change is a major challenge for Cambodian smallholder farmers reliant on rainfed rice-based agriculture. However, by 2050 climate change is predicted to reduce the national rainfed rice cultivation area by 20%. Replacing a traditional low input transplanted rice crop with a 'response farming' approach has potential to not only mitigate effects of current seasonal variability but enable farmers to transition their farming practices in response to future climate uncertainty. It is assumed that a number of strategies are available to farmers in response to the timing, intensity and longevity of the monsoon period and that a particular mix of options better suit the specific and unfolding seasonal conditions that a farmer faces in a given season is more appropriate than rigid traditional practice in realising livelihood goals. This approach is based on utilising improved, shorter duration varieties, more efficient establishment methods and better agronomic management. Well-tested biophysical models have been successfully employed in investigating impacts of projected climate change on food production at global (Rosenzweig and Parry, 1994), regional and country (Ruane et al, 2013) scales and are a cost effective method for evaluating possible adaptation strategies available to farmers in managing current and future climatic risk. The APSIM-Oryza model (Gaydon et al., 2012) has been calibrated and validated for transplanted and direct seeded rice for current climatic conditions (Poulton et al. 2015). This analysis investigates the risk from projected climate change at the IPCCs 2060 time horizon, on rainfed and irrigated rice production in Southern Cambodia and explores the impacts of some adaptation strategies on future rice yields in the region.

Methods
Baseline climate was generated from local observations (1997-2011) and downscaled GCM data using a 'Linear Mixed-Effect State-Space' model applied to produce effective point scale projections suitable for use

in bio-physical modelling (Kokic et al., 2011). APSIM-Oryza was parameterised for a short duration rainfed rice crop and run for incremental changes to CO_2 (380 – 830 ppmv), ambient temperature (28.06 – 34.06 °C), rainfall (-20% – +20%) and for 9 combinations of all three climatic factors (rainfall -20% – +20%, CO_2 -118% – +118%, temperature -21% – +21%) to evaluate model response for a given set of input parameters. A multi-factor sensitivity analysis was then applied to assess potential variation from current baseline yields for IPCC projected scenarios of 0.7 – 2.7 °C change in ambient air temperature and a 31.0 – 64.0% increase in atmospheric CO_2 to 2060 for the Cambodian region. Three scenarios compared a traditional transplanted medium duration rice variety (MSTR) with a 'response' farming approach using a modern direct seeded short duration variety grown under rainfed (SSDR) and irrigated (SDDI) conditions under scenarios involving a combination of changes to temperature and CO_2 previously described and ±15% change in annual rainfall. Results are presented as a series of probability of exceedence graphs showing the difference in rice yield as a percentage change from baseline or current yields (defined as 0% on the x axis) for each scenario. The percentage of years experiencing a crop failure is indicated by a -100% change from baseline yield on the x axis. Climate scenarios projected to 2020, 2040 and 2060 are presented.

Results and Discussion

Model response to elevated CO_2 of 680 ppm for current temperature and rainfall is consistent with the accepted physiological effects of CO_2 on C3 crops, simulating a 17.5% yield increase above baseline levels. Figure 1 demonstrates results of sensibility testing of the model for incremental changes to ambient temperature, CO_2 concentration and rainfall all within the IPCC projected range for climate change for the Cambodian region to 2090. The modelled yield response is comparable with Li et al. (2014), for 13 rice models, reporting a 7% to 11% (APSIM 6.11%) increase per 100 **µ**mol mol^{-1} for the 380 – 480 ppm CO_2 range and 3% to 5% (APSIM 4.13%) for the 630 – 730 ppm range and a reduction in yield of 2% to 11% (APSIM 4%) per degree C increase above the baseline temperature. Simulated long-term mean yields of 3.65 t ha^{-1} (MSTR), 4.64 t ha^{-1} (SSDR) and 5.16 t ha^{-1} (SDDI) for 380 ppm CO_2 and 1997 – 2011 temperature and rainfall are the basis for directly comparing the resilience of the selected management scenarios for projected increases in temperature and CO_2 for the period 2020 – 2060 and changes in annual rainfall of -15% (a), 0% (b), +15% (c). Baseline yields are comparable with on-farm yields observed in 3 years of experimentation to 2014 (data not shown). For the 15% decline in annual rainfall example, for 2020 (Figure 2 MSTR (a)), the probability of a crop failure occurs in 39% of years and increases to 42% by 2060. Years exceeding baseline yields declined from 24% (2020) to 15% (2060). In comparison, for a 15% increase in annual rainfall in 2020 (Figure 2 SSDR (c)), the probability of crop failure occurs in only 9% of years.

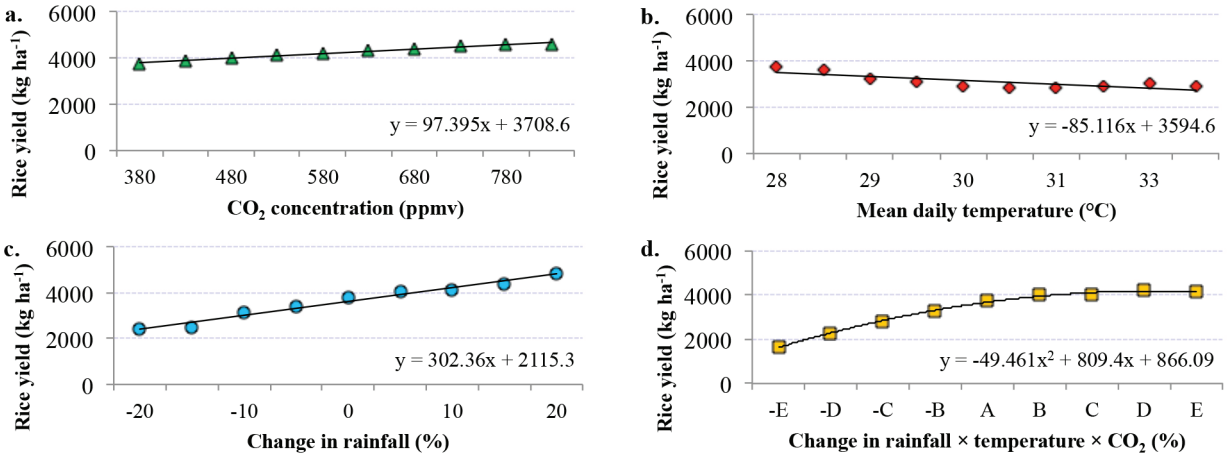

Figure 1. Mean yield response of APSIM to incremental changes in (a) CO_2 concentration above 380 ppmv, (b) mean daily temperature above a baseline temperature of 28.06 °C, (c) rainfall of ± 20 % of baseline rainfall; and (d) combined climate factors (rainfall -20% (-E) – +20% (+E), CO_2 -118% (-E) – +118% (+E), temperature -21% (-E) – +21% (+E)) for a single direct seeded short duration rice crop planted after May 1. Results based on incremental adjustment of baseline climate for 1978 – 2011.

For this scenario baseline yields are exceeded in 55% of years but decline to 42% by 2060. While crop failure remained relatively static within each rainfall scenario, yields fell in response to the combination of higher temperature and CO_2, particularly with declining rainfall. A 15% increase in rainfall and elevated CO_2

partially offset the effect of increased temperature on crop development whereas a reduction in rainfall of 15% results in a 40% yield penalty. Access to irrigation mitigates the effect of climate extremes, reducing risk of crop failure and improving yields for all rainfall scenarios in 60% to 85% of years (Figure 2. SDDI a-c). Except for the wetter climate scenario (+15%) where additional rainfall offsets the irrigation required to maintain current yields until 2040, a significant investment in irrigation infrastructure or improved water use efficiency will be required to maintain existing rainfed yields in response to increasing temperature by 2060. In comparison, use of supplementary irrigation early in the season has been shown to support successful early crop establishment and development during the critical growing period and delivers the opportunity for a second crop and therefore higher on-farm returns. For a 15.7% increase in CO_2 by 2030, early crop establishment and use of modern rice varieties and improved N fertiliser management can double production compared with traditional systems utilising low input late maturing local varieties.

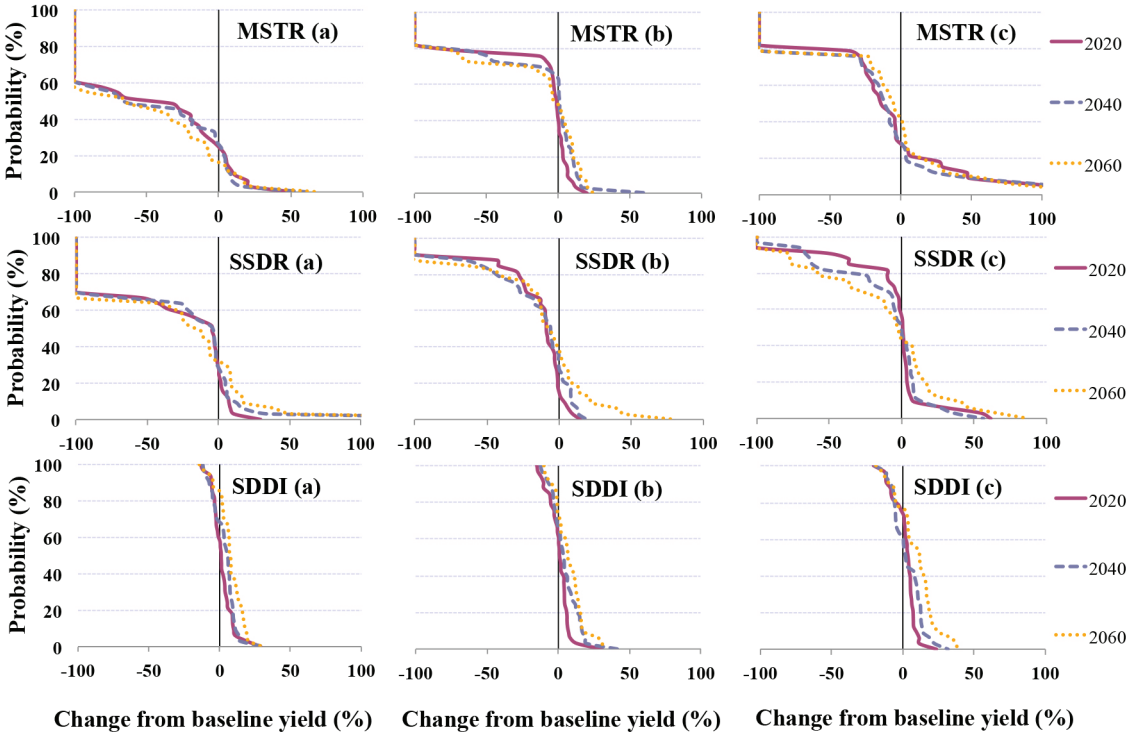

Figure 2. Probability of exceeding baseline yields (0% on X axis) for current ambient air temperature and 380 ppm CO_2, for a rainfed transplanted single medium variety (MSTR), rainfed single direct-seeded short variety (SSDR) and irrigated double cropped direct-seed short variety (SDDI) in response to projected increase in temperature and CO_2 and for a changes in annual rainfall of (a) -15%, (b) 0%, (c) +15% for 2020, 2040, 2060.

Conclusion

The response of APSIM-Oryza to elevated temperature and CO_2 is consistent with measured physiological CO_2 effects on C3 crop yields and is comparable with results from similar crop modelling studies. For Cambodian smallholder farmers, traditional rainfed rice production beyond 2030 is at risk from increased variability in the distribution and timing of rainfall. The long-term resilience of a 'response farming' approach in managing seasonal variability is demonstrated by a reduction in crop failures when compared with traditional transplanted practice. Adoption of direct seeding of higher yielding, short duration rice varieties; access to mechanical harvesting; improved nitrogen management; use of supplementary irrigation at sowing, and/or better utilisation of available water, all support early crop establishment and deliver farmers additional strategies for maintaining and potentially increasing rice production in response to future climate uncertainty.

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Validation of APSIM for long duration rice varieties in different agro-climatic zones of Sri Lanka

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Abstract
Rice (*Oryza sativa* L.) is the staple food for many Asians. In Sri Lanka, rice production is heavily dependent on the rainfall distribution pattern, and would be adversely affected by climate change. Prediction and estimation of yield and resource-use efficiency of commonly grown rice varieties is of immense importance under a variable and changing climate. Agricultural system simulation models are useful tools to assess the performance of agricultural systems under scenarios of changing rainfall patterns. The present study was conducted to validate the Oryza module of the Agricultural Production Systems Simulator (APSIM) model for two long duration rice varieties, Bg403 and Bg379-2 (4 months maturity). Model evaluation was done using secondary data. APSIM simulated the observed rice yields for Bg403 and Bg379-2 with a strong fit (R^2 of 0.88 and 0.77, respectively, and CV of 9.9% and 14.4%, respectively). Yield was less when grown under rainfed condition than under irrigation for both the varieties. The highest simulated yield loss was observed at Aralaganwila (Dry-Zone Low Country), where a 10% reduction in the seasonal rainfall was simulated. The validated APSIM-Oryza module can be used in evaluating the potential areas for rice cultivation in Sri Lanka under current and predicted climate change scenarios.

Key words
Low-land rice, Productivity, Water scarcity

Introduction

Rice (*Oryza sativa* L.) is the staple food for Sri Lankans. Total land devoted to rice is estimated to be about 805,647 ha (Agstat, 2013). Rice varieties are categorized into three types according to the time taken for maturity: short duration (up to 3 months), medium duration (3-4 months months), and long duration (4-4.5 months). Rice varieties in the short and medium duration age classes collectively comprise over 93% of the rice production of Sri Lanka and the balance is long duration varieties (Agstat, 2013). Due to heavy and longer duration rainfall during *Maha* season (major rainy season from October to February), farmers cultivate long and medium duration rice varieties. Short duration rice varieties are cultivated during the *Yala* season (minor rainy season from March to September) when the availability of water is limited. Long duration rice varieties are reported to give higher yields than other types. The total land area devoted to rice is not usually cultivated due to a shortage of water during the season (DCS, 2011). Global climate change projections have raised concerns about the negative impacts on crop production in Sri Lanka (Weerakoon and De Costa, 2009). Therefore, it is important to identify the ways of improving national rice production to meet the rising demand of an increasing population.

Estimation of rice yields are needed for different management conditions, and one approach to achieve this is by using crop models. The APSIM-Oryza was developed by incorporating the ORYZA2000 rice growth model (Bouman and van Laar, 2006) into the APSIM modelling framework. The model has been used in Sri Lanka, to evaluate the nitrogen response in lowland rice (Suriyagoda and Peiris, 2011), and for assessing the yield advantage and water productivity when aligning planting date with the onset of rainfall using short and medium duration rice varieties (Amarasingha *et al.*, 2014). The objectives of this study were to (i) validate APSIM-Oryza module for two long duration rice varieties widely grown in Sri Lanka (Bg379-2 and Bg403), (ii) estimate the rice yield in the Dry and Intermediate Zones with and without irrigation water availability

during the *Maha* season and, (iii) estimate the rice yield of long duration rice varieties when rainfall is reduced by 5 % and 10 % during the *Maha* season.

Materials and Methods

APSIM model

The Agricultural Production Systems Simulator (APSIM) version 7.4 was used to validate the phenology and growth of long duration rice varieties Bg379-2 and Bg403 in four locations in different agro-climatic zones in Sri Lanka namely, Maha-Illuppallama (MI; Dry Zone, Low-Country), Bathalagoda (BG; Intermediate Zone, Low-Country), Bombuwela (BW; Wet Zone, Low-Country), and Aralaganwila (AG; Dry Zone, Low-Country). APSIM was previously parameterised for the above rice varieties (Fernando, 2014)

Data for model calibration and evaluation

Secondary data collected for over twenty years from both *Yala* and *Maha* seasons included planting date, time taken for flowering, 50% heading and maturity, and yield. These data were sourced from the Rice Research and Development Institute (RRDI) at BG and its regional station at BW, and the Field Crop Research and Development Institute (FCRDI) at MI and its regional station at AG under the National Coordinated Rice Variety Trials (NCRVT). Daily weather data (maximum and minimum temperatures, rainfall, and solar radiation) from 1976 to 2011 for MI, 1993 to 2013 for BG, 2002 to 2012 for BW, and 2001 to 2012 for AG were obtained for both *Yala* and *Maha* seasons from the Natural Resource Management Centre (NRMC) of the Department of Agriculture (DOA). Soil characteristics of the study sites were obtained from Mapa *et al*. (2010).

Management practices

All crop management practices were conducted according to the recommendations of the DOA (DOA, 2014). Planting dates and planting methods (direct seeding), irrigation, and fertilizer management strategies were parameterised in the model simulations as recorded from the sites. In the simulation process, a maximum ponding depth of 8.0 cm of water was maintained in the field either through rainfall or irrigation. Irrigation water was available only at the MI, BG, and AG and therefore, model simulations were run with supplementary irrigation for those sites. At the BW site, irrigation water is not available and hence simulations were run as a rainfed system.

Definition of the scenario modelled

Rainfall distribution may change as predicted by the climate change models. Specifically, the reduction in amount of rainfall received during *Maha* season may affect rice production. The simulated scenarios were:

> *Scenario A: With and without irrigation*
> Simulations were run with supplementary irrigation and without (*i.e.* rainfed).
>
> *Scenario B: Reduced rainfall in the Maha season*
> The weather files of the BG, MI, AG and BW sites were changed to reduce the daily rainfall by 5% and 10%. The *Maha* season is the major rice cultivating season in the Dry and Intermediate Zones.

Results and Discussion

The model could simulate the time taken for 50% flowering of Bg403 and Bg379-2 varieties in different locations. The CV values for Bg403 and Bg379-2 were 2.6% and 3.2%, respectively. The RMSE values for Bg403 and Bg379-2 varieties were 2.2 and 3.0 days and the R^2 values were 0.71 and 0.70, respectively (Fig. 1).

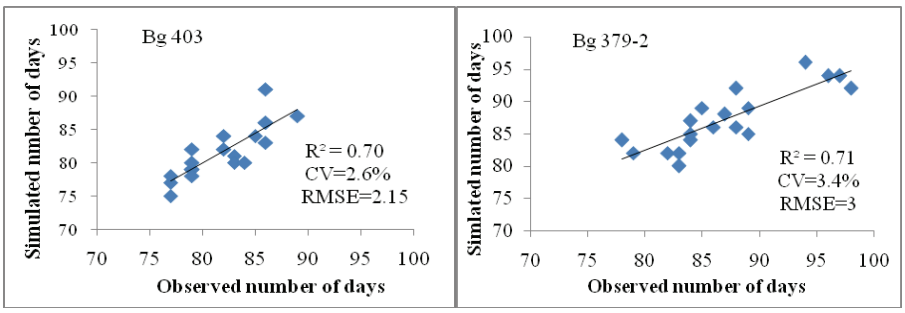

Figure 1. Observed and simulated days required for 50% flowering of Bg403 and Bg379-2 rice varieties grown during *Yala* and *Maha* seasons at Maha-Illuppallama, Bathalagoda, Aralaganwila and Bombuwela, in Sri Lanka.

The model estimated the rice yield at different locations with a strong fit. For Bg403 and Bg379-2, R^2 values were 0.89 and 0.77, respectively while the CV values were less than 15 % (Fig. 2). Therefore, this model can be used to predict the grain yield of Bg403 and Bg379-2 with high accuracy.

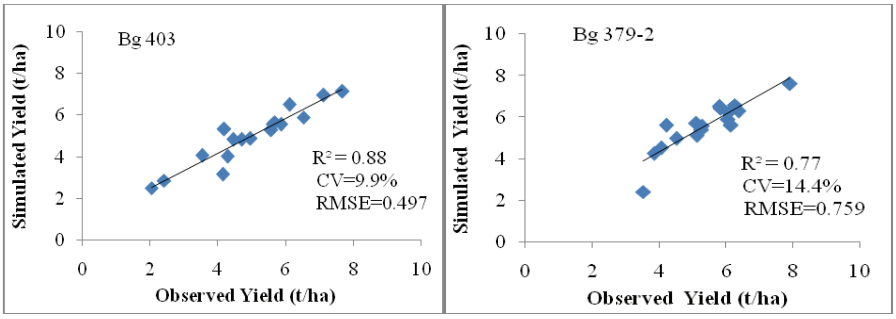

Figure 2. Observed and simulated grain yield of Bg403 and Bg379-2 rice varieties grown during *Yala* and *Maha* seasons at Maha-Illuppallama, Bathalagoda, Aralaganwila and Bombuwela, Sri Lanka.

There was a wide variability in soil physical and chemical properties among different locations (Mapa *et al*., 2010). Even under such variable conditions the parameterized APSIM-Oryza model could estimate the grain yield of rice with a high accuracy. The average expected grain yield of long duration rice varieties is higher than the short and medium duration rice varieties. However, due to various reasons, the yield potential of those varieties has not been achieved under field conditions. As APSIM-Oryza can incorporate the changes in soil moisture, nutritional aspects, and agronomic management decisions, the validated model can effectively be used in exploring yield-limiting factors. In these simulations supplementary irrigation was available when estimating the yields at MI, BG, and AG if the rainfall was not adequate; whereas at BW rice yield was simulated as a rainfed crop. Therefore, the different sites and years represented varying levels of soil moisture stresses which was a major factor affecting low observed yields across locations and years. Even under such diverse soil moisture availabilities, APSIM-Oryza could simulate the grain yield with a strong fit.

The highest observed yields were recorded at AG (Bg 379-2: 5.9 t/ha and Bg 403: 6.1 t/ha). The model can be used to estimate the expected yield under different management conditions such as a reduction in irrigation water availability. At BW, the observed yield recorded was lower than other locations tested (Bg 379-2: 4.5 t/ha and Bg 403: 3.2 t/ha). Possible agronomic interventions can be tested using simulation models to understand whether rice productivity can be improved through different management decisions. The precision achieved for the long duration rice varieties in this study is comparable with or even better than the level of precision reached by Amarasinghe *et al*. (2014) for short and medium duration rice varieties grown in in Sri Lanka.

Scenario analyses

The validated model was used to simulate yield performances under different scenarios. In the simulation of Scenario A (with and without irrigation), the yield was reduced at all the sites, with the greatest reduction at BG (69 % reduction) (Fig. 3A). At AG the yield reduction was less (15 %) than that observed at MI (50 %).

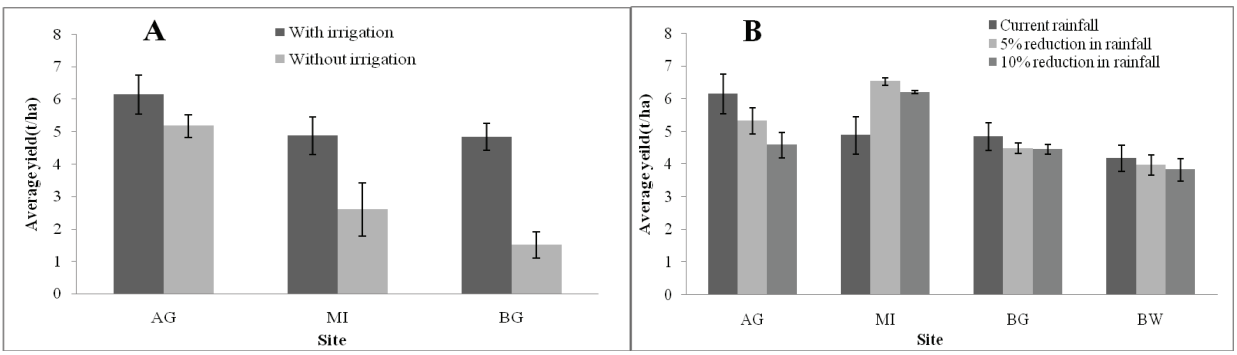

Figure 3. Average yield of rice with and without access to irrigation water supply (A), and under different levels of rainfall (B) during *Maha* season at Aralaganwila (AG), Maha-Illuppallama (MI), Bathalagoda (BG) and Bombuwela (BW) in Sri Lanka. Vertical lines indicate the standard error of the means, n=10.

The reason for the greater dependency of irrigation water at BG is due to the lower amount of rainfall received during the *Maha* season (average rainfall of 587 mm, n=10) than that received at AG (average rainfall of 1346 mm, n=10). The dependency of irrigation water can be reduced at least partly if the planting date is adjusted with the onset of rainfall season (Amarasinghe *et al*., 2014).

The average rice yield was reduced at all the sites except at MI when the simulated amount of rainfall was reduced by 5 % and 10 % below recorded data. The AG site experienced the greatest reduction in grain yield with the reduction in rainfall (Fig. 3B) and thus would be more affected by a possible reduction in rainfall in the future. At BG and BW sites, the reduction in grain yield was less than 8 % and 10 % when rainfall was reduced by 5 % and 10 %, respectively. Rice productivity increased at MI, and the exact reason for this response is not known and needs to be assessed further.

Conclusion

The APSIM-Oryza model was evaluated with high precision for two long-duration rice varieties (4 months to maturity; Bg403 and Bg379-2) for different agro-climatic zones in Sri Lanka. The capability of the model to simulate the time required for 50 % flowering, physiological maturity, and grain yield for both rice varieties was satisfactory

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Entry points for eco-efficient aerobic rice production system in Punjab, Pakistan

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Abstract
Major issues challenging the sustainability of conventional flooded rice systems in Pakistan are: low input conversion efficiencies, productivity stagnation, rising costs of production, and shortage of water, labour, and energy. An emerging opportunity is an alternative, eco-efficient production system called 'aerobic rice', which entails the growing of direct-seeded crops in non-puddled fields under non-flooded conditions. Eco-efficiency is about achieving more agricultural output per unit of input, through substitution of production factors including knowledge. We evaluated the aerobic rice system in Punjab, Pakistan from biophysical and socio-technological perspectives employing a combined approach of experimentation (i.e. field trials on resource-use efficiencies and growth chamber studies on phenology) and farmer surveys. Our findings suggest that the aerobic rice system is a rational approach for improving the eco-efficiencies of water, labour, and energy. However, for subtropical conditions, the knowledge-intensive system is still very much in the development phase, thus requiring a thorough understanding of the entry points (i.e. opportunities and threats). Based on our findings, the entry points for aerobic rice systems are: availability of fine grain *basmati* varieties; savings on water, labour, and energy; net profitability; extension outreach programmes to raise awareness among farmers; good quality biocides; prospective areas for crop diversification; optimisation of agronomic practices such as seed rate, water, and fertiliser inputs; land levelling; and mechanical interventions for appropriate seeding and weeding. In order to balance production and sustainability, risks of crop failure can be reduced by optimisation of scarce resources and provision of suitable genotypes.

Key words
Resource-use efficiency; rice systems; transformational technology; Punjab; Pakistan.

Introduction
Water is becoming scarcer than land in Pakistan. Water productivity of different crops is among the lowest in the world. Current practices in some parts must transition to water-saving systems for sustainable crop production, in particular for *'water-guzzling'* crops like rice. Rice crop, essentially grown on irrigated fields in Pakistan, covers 2.6 million hectares (Mha) with an annual production of about 6 million tonnes. Rice-based cropping systems are rice-wheat, rice-berseem, rice-pulses, rice-vegetables and rice-fallow (GOP, 2014; Chapagain and Hoekstra, 2011). The rice-wheat system covers 2.2 Mha and is the second largest cropping system after cotton-wheat. Paddy rice is typically grown by transplanting 30–35 day old rice seedling in continuously flooded conditions with ponding depths of 50–75 mm for most of the growing season, requiring 15 to 25 irrigations. Total water application ranges from 1200 to 1600 mm over a 100–150 day growing period. (Ahmad *et al.*, 2007). The stagnation of productivity threatens the sustainability of intensive systems via the degradation of soil and water resources. Water shortage, low plant population per unit area due to labour shortage at critical time of transplanting, falling water tables and concomitant rise in energy requirement for pumping groundwater are the major limitations for rice production. With low income generating ability and low conversion efficiencies for the scarce inputs, the conventional transplanted-flooded rice system is now showing its limitations for resource poor farmers. (Farooq *et al.*, 2011; Ladha *et al.*, 2003).

Emerging global resource constraints have led to a renewed focus on improving the overall eco-efficiencies of agricultural systems (Keating *et al.*, 2010). Conceptually, eco-efficiency is achieving more agricultural outputs in terms of quality as well as quantity with less inputs of land, water, nutrients, energy, labour, or capital, thus covering both the ecological and economic aspects of sustainable agriculture. An emerging opportunity is an alternative and eco-efficient productions system called 'aerobic rice'. Aerobic rice entails the growing of direct-seeded rice crop in non-puddled fields under non-flooded conditions throughout the

growing season. We used the term 'aerobic rice system' for the whole package of agronomic practices and biophysical and socio-economic boundary conditions. Aerobic rice could considerably improve eco-efficiencies in rice-based systems where water, labour, and energy are becoming increasingly scarce. The aerobic rice system is gaining momentum in South Asia as an alternate to the conventional transplanted-flooded rice system (Mahajan *et al.*, 2013). Under Pakistani conditions, water economy is the main driver behind aerobic rice systems. Changing the current production system to non-flooded aerobic rice could considerably increase resource use efficiencies. However, for subtropical conditions, such as those in Pakistan, the non-conventional system is still very much in the development phase.

Aerobic rice systems are knowledge-intensive thus requiring careful management interventions, heavily relying on biocides for managing weeds and nematodes. Essential plant nutrients (e.g. N, P, K, Fe, Zn, and Mn) may become deficient under aerobic conditions (Kreye *et al.*, 2009). Management practices should be developed to enhance resource-use efficiency especially for water and nitrogen (N) which are the most limiting factors. Accurate prediction of the timing of different events in plant development is crucial to facilitate timely resource application, which is crucial for optimising resource use of scarce inputs. In this paper we outline the main entry points (i.e. opportunities and threats), which are critical for further technology development and dissemination.

Approach

This paper is based on an interdisciplinary project (Awan, 2013). In the interdisciplinary project, we employed a combined approach of experimentation and farmer surveys to contribute important information on aerobic rice crop performance, preflowering photothermal responses, and farmers' perspective. Two seasons of field experiments (2009 and 2010) at the research station of the University of Agriculture, Faisalabad–Pakistan tested three local (KSK133, IR6, RSP1) and two exotic (Apo, IR74371-54-1-1) genotypes against different combinations of irrigation levels (Total water input through irrigation and rainfall in 2009-10: 1278-1318 mm (high), 934-979 mm (moderate), 701-938 mm (low)) and nitrogen (N) rates (0, 170, 220 kg N/ha) under aerobic conditions. The experimental site lies in the non-traditional rice belt, which is an important target domain for aerobic rice. Understanding phenology × environment interactions is essential to devise management practices that improve resource use efficiency in environments with sub-optimal resource supply. To disentangle photoperiod (PP) and temperature effects, we used a two-step approach. The PP-response was determined in growth chambers, through a reciprocal transfer experiment with variable daylength (10, 12.5 and 15 h/d) conducted at a fixed temperature of 26°C. Consecutively, the temperature response was determined by combining the obtained PP-parameters with data from field experiments. To supplement the basic biophysical research, we conducted farmer surveys in three major cropping systems of Pakistan Punjab viz. rice-wheat, mixed-cropping and cotton-wheat to understand farmers' views about the future prospects of aerobic rice system. Respondents (n = 215) were grouped using two criteria: (1) their current cropping system and (2) their experience with rice and specifically aerobic rice system. The second criterion led to a distinction between three groups: group I (n = 70) were informant farmers from the rice–wheat system who had tried aerobic rice in a participatory research trial in 2010; group II (n = 97) were rice-growing farmers from each cropping system who did not participate in the trials; group III (n = 48) were non-rice-growing farmers with experience in mixed-cropping or the cotton–wheat cropping system (Awan et al., 2015). Based on the results of the interdisciplinary project and relevant information on aerobic rice experiences in other parts of the world, we have identified the key entry points in this paper.

Key findings and their implications

Eco-efficiencies of water, N, labour, and energy

Grain yield (GY) is a basic measure of eco-efficiency. The GY levels of tested genotypes were generally within the target GY of 4–6 t/ha for aerobic rice systems i.e. 80% GY attainable under transplanted-puddled rice system. Under aerobic system, the GY penalty in Pakistan and India ranged between 7.5–28.5% (Kumar et al., 2011). The exotic genotypes (Apo and IR74371-54-1-1) better coped with water stress, clearly lowering the risk of obtaining low GY. Under different irrigation regimes, the exotic genotypes recorded GY (t/ha) levels of 4.34 (high), 3.57 (moderate), and 2.64 (low) respectively as against the GY levels (i.e. 4.56, 2.55, 1.78) of the benchmark local genotype KSK133. The exotic genotypes clearly lower the risk of obtaining low GY under water stress conditions but under more optimal water supply conditions the local genotype

KSK133 was better. Under aerobic system, we found water productivity (WP_g; g grain/kg total water input through rainfall and irrigation) values of up to 0.38, which is more than double the national average of 0.16 for the conventional flooded system in Pakistan. Compared to the gross water requirements of 1600 mm, the total water use (~1300 mm in the high irrigation treatment) resulted in a 20% water savings, which might save farmers three to four irrigations and also reduce energy requirements for pumping groundwater through diesel or electric pumps. Farmers ranked labour savings in direct-seeded aerobic system higher than water saving. Under subtropical, semiarid conditions as in Pakistan, producing more rice per unit area and with less water is rarely possible: reduced water input in our study increased WP_g but decreased the GY compared to the flooded system. Pakistan is one of the most water-stressed countries in the world, hence aerobic systems are more advantageous in terms of saving both water and labour compared to the direct seeded rice systems, which mainly focus on labour saving. The GY was positively correlated with total N uptake but we found small differences between the three N application rates, which suggest that a significant amount of the applied N was not taken up by the crop. The process of alternate wetting-drying is known to stimulate the decomposition of soil organic matter and nitrification–denitrification processes. Although we have insufficient experimental data to quantify the complete N (and hence energy) balance, we hypothesise that atmospheric N losses were a major factor in the overall N balance (Awan et al., 2014). In aerobic systems, the improved eco-efficiencies of water, labour, and energy might happen at the cost of declined efficiencies for N and land.

Resource-use in relation to phonological development

All four tested genotypes (KSK133, RSP1, Apo and IR74371-54-1-1) were PP-sensitive. The crop duration (i.e. sowing to maturity) extended under aerobic conditions. The extended crop duration under aerobic conditions is probably one of the reasons for failure of long duration fine grain *basmati* genotypes under limited irrigation regimes like aerobic rice. Since the crop duration has direct implications for resource use and the sowing window, aerobic rice genotypes should be early-maturing. The significant variation in optimal flowering time and PP-sensitivity among tested genotypes could be exploited by breeders to develop genotypes that can avoid adverse environmental conditions such as pre- and post-monsoon drought. A good understanding of developmental processes such as PP-sensitivity and their interactions with other environmental factors (temperature, water, and N, in particular) is essential to avoid resource limitations during critical growth stages.

Farmers' perspective

More than half of respondents never heard of aerobic rice; yet most of them (76%) were positive about trialling the non-conventional aerobic rice system. Rice farmers, who have already heard about aerobic or dry direct-seeded rice, often call it broadcast or dry rice which reflects their appreciation for either shrinking labour or water resources. The most often mentioned positive attribute of aerobic rice was reduced labour requirement followed by water saving. Other positive attributes were: ease of operation due to direct seeding instead of laborious puddling and transplanting activities; good income; improved physical condition of the soil. The negative attributes or the associated risks were: weed infestation; diseases; increased spikelet sterility; poor germination; higher irrigation frequency; more seed rate; unavailability of suitable varieties; GY penalty (Awan et al., 2015). The greater water use efficiencies (yield per unit of water) are often associated with lower land use efficiencies (yield per unit of land). An optimal system is then a system that maximises resource use efficiency of the most limiting resource (in this case water) while keeping possible efficiency losses for other resources within acceptable limits.

Entry points for aerobic rice systems

To feed over nine billion people by 2050, agricultural systems will rely on transformational technologies. For rational use of scarce resources, 'knowledge' as a production factor will play a decisive role. Aerobic rice is a knowledge-intensive technology that requires precise/timely management practices. Identifying the knowledge-based entry points can answer this basic question: how can aerobic rice technology pick up momentum to be able to spread in the target domains? Our interdisciplinary study underpins the potential for increasing use-efficiency of scarce resources of water, labour, and energy. However, the aerobic rice technology is still evolving and much needs to be done to increase its adoption rate. Identification of the technological and knowledge gaps can value add to the on-going research on water-saving rice cultivation. Farmers need to be educated through extension activities to raise awareness about the non-conventional

system and to tackle the associated risks like weed infestation. Field level studies on resource-conservation technologies documented the potential for water saving. To upscale the results at basin level, there is a need to adopt the required precursor technologies (e.g. laser land levelling) and to identify alternate uses of saved water. For example, the saved water can be used rationally for bringing more area under rice cultivation, thus compensating for yield penalty under aerobic rice systems. With the extension of irrigation system e.g. development of a 'Greater Thal Canal' in a region supporting pulses-based cropping systems, there is a need to identify alternate crop rotations, which might give a niche for aerobic rice systems.

Improved eco-efficiencies of water, labour, and energy might happen at the cost of declined efficiencies for N and land. Eco-efficient N management strategies (e.g. using composts and farmyard manure) and bringing the culturable wasteland under cultivation by provision of the saved irrigation water are some of the proposed measures for improving the productivity and sustainability of agricultural systems. Currently, the non-traditional rice belt of Punjab and Sindh province are the main target domains as coarse grain non-basmati varieties, which are comparatively better adapted to aerobic conditions, are grown there. In the typical rice belt of Punjab, the abode of world's famous aromatic *basmati* varieties, non-availability of well-adapted aerobic varieties of *basmati* rice is a major constraint for expansion of the aerobic rice systems. The on-going breeding efforts should screen rice germplasm for developing *basmati* varieties adaptable to heat and water stress conditions. Based on the results of farmer surveys, farmers already growing rice, in particular those having large size of landholding and farms with clayey soil types are most likely to be early adopters of the technology. Introduction and dissemination of aerobic rice technology will depend on filling the technological gaps: mechanical interventions for seeding and weeding; good quality biocides; optimisation of agronomic practices such as seed rate and balanced nutrition; quantitative estimation of potential areas for intensification or crop diversification.

Conclusion

Aerobic rice is a viable eco-efficient option to improve water productivity in regions like Pakistan where water is getting scarcer than land. The developing technology will benefit from well-informed knowledge-based entry points to fill the identified technological and attitudinal gaps.

Acknowledgement

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Field-screening for crop adaptation to heat stress: untangling confounded effects of sowing date trials

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Abstract
We need reliable methods to screen genotypes adapted to elevated temperature. Sowing date experiments are practical and inexpensive but confounded factors limit their value. First, mean temperature correlates with both minimum and maximum temperature, photoperiod, radiation and vapour pressure deficit, and it may also correlate with rainfall. Second, temperature alters the genotype-dependent phenology of crops, effectively shifting the timing and duration of critical periods against the background of temperature and other environmental variables. Our aim is to advance a framework to untangle the confounded effects of sowing date experiments; it is based on four physiological concepts: (1) annuals accommodate environmental variation through seed number; (2) seed number is determined in species-specific developmental windows; (3) non-stressful thermal effects affecting seed set through development and canopy size can be integrated in a photothermal quotient (PTQ), (4) stressful temperature reduces yield by disrupting reproduction. The framework was tested in a factorial experiment combining four chickpea varieties and five environments resulting from the combination of seasons and sowing dates. The environment-driven, genotype-dependent shifts in phenology led to different conditions in the critical window (between flowering and 400oCd after flowering) for each variety-environment combination. Yield ranged from 13 to 577 g m-2. The PTQ explained 50% of yield variation and maximum temperature for 32% of the remaining variation. Thus, half of the variation in yield was associated with developmental, non-stressful photothermal effect and (at most) 16% of the variation was attributable to thermal stress. The PTQ corrected by vapour pressure deficit explained 75% of the variation in yield and provides further insight on photosynthesis-mediated responses to temperature.

Key words
Chickpea, radiation use efficiency, vapour pressure deficit, phenology, breeding

Introduction
Sowing date experiments have been used to investigate thermal effects on crop traits including grain yield. This method is practical, inexpensive and allows for comparisons of large collections of lines. However, this approach is indirect and therefore inconclusive; rankings of varieties as a function of the difference in yield between late and early sown crops are likely to be biased. Late-sown crops normally experience hotter conditions and phenotypes thus partially capture this environmental influence. There are, however, two important sets of confounded factors in sowing date trials. First, daily mean temperature correlates with both minimum and maximum temperature, radiation, photoperiod and vapour pressure deficit, and it may also correlate with rainfall. Sowing date changes the pattern of supply and demand for both water and nitrogen. Second, temperature alters the genotype-dependent phenological development of crops, effectively shifting the timing and duration of critical periods against the background of temperature and other environmental variables (Fig. 1A).

Here we advance and test a crop-level framework to unscramble the confounded effects of sowing date experiments. The framework, outlined in Fig. 1B, is based on four physiological concepts: (1) annual crops accommodate environmental variation through seed number rather than seed size; (2) seed number is most responsive to the environment in species-specific developmental windows; (3) non-stressful thermal effects on seed set mediated by development, canopy size and radiation interception can be integrated in a photothermal quotient relating intercepted photosynthetically active radiation (PAR) and mean temperature during the critical window (Fischer 1985); (4) stressful temperature reduces yield by disrupting reproduction. The framework was tested in a factorial experiment combining four chickpea varieties with putatively contrasting adaptation to heat stress and five environments resulting from the combination of seasons and sowing dates.

Method
Fully irrigated crops were grown on a vertisol at ICRISAT, India during two seasons, 2012/13 and 2013/14. A factorial experiment combined four chickpea lines and five environments corresponding to two sowing

dates (1/11/12 and 1/1/2013) in season 1 and three sowing dates (2/11/2013, 22/11/2013 and 20/12/2013) in season 2. Two heat-tolerant chickpeas ICCV 92944 and ICC 1205 were compared with two sensitive lines, ICC 4567 and ICC 5912.

Phenology was recorded twice a week. At maturity, 3.0 m2 samples were taken to determine yield and its components. PAR interception was measured with a ceptomer three times each week in each replicate. Polynomials were fitted to characterise the dynamics of PAR interception during the growing season and used to derive daily PAR interception, cumulative PAR interception during the critical period of yield determination and cumulative seasonal PAR interception. Radiation use efficiency was calculated as the ratio of shoot biomass at maturity and seasonal PAR interception.

We calculated a photothermal quotient PTQ (Fischer 1985) as the ratio between intercepted PAR and mean temperature for the critical window of yield determination between flowering and 400 oC d after flowering (Lake and Sadras 2014); base temperature = 0 oC was assumed. A photothermal quotient corrected by vapour pressure deficit PTQvpd was calculated as the ratio between PTQ and mean VPD during the critical period (Rodriguez and Sadras 2007). In the present study, crops were grown in a single location during the dry season where variation in fraction of diffuse radiation was considered to be minor compared to the variation in VPD, hence we did not include a correction by fraction of diffuse radiation that may be important to account for latitudinal gradients.

To test our conceptual model (Fig. 1B) we fitted linear regressions: yield vs PTQ and yield vs PTQvpd. Residuals were analysed to test for effects of maximum temperature as an indicator of thermal stress, variety, environment and other crop traits.

Results

All three sources of variation, i.e. variety, environment and their interaction, influenced time of flowering and time of maturity (all $P < 0.0001$). The environment-driven, genotype-dependent shifts in phenology led to weather conditions in the critical window that were different for each variety-environment combination.

Yield ranged from 13 to 577 g m-2 and was affected by all three sources of variation: variety, environment and their interaction (all $P<0.0001$). The photothermal quotient during the critical period, PTQ, accounted for half and the PTQvpd for three quarters of the variation in yield (Fig. 1AB). Seed number explained the variation in yield in response to PTQ and PTQvpd as expected from theory (Fig. 1CD).

The numerator of PTQ accounts for intercepted radiation but variation in crop photosynthesis per unit intercepted radiation may contribute to the scatter of the relationship between yield or seed number and PTQ. Radiation use efficiency was inversely related to vapour pressure deficit and maximum temperature (Fig. 1EF). Hence, vapour pressure deficit and maximum temperature may have contributed to the reduction in scatter of the relationship between PTQvpd and seed number (Fig. 1 C vs D) and yield (Fig. 1 A vs B) in comparison to PTQ.

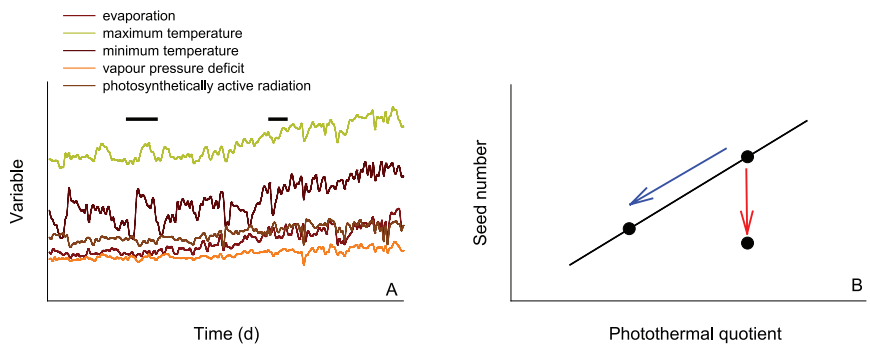

Figure 1. (A) Sowing date experiments shift and change the duration of the critical period of yield determination (black segments) and confound stressful and non-stressful thermal effects and other factors. (B) Framework to unscramble two types of thermal effects: non-stressful, mediated by phenology and canopy size (blue arrow) and stressful, mediated by reduced photosynthesis per unit intercepted radiation, reproductive failure or both (red arrow).

Residuals of the relationship between yield and PTQvpd increased with individual seed weight (Fig. 2A). This is consistent with the dominant role of seed number and the secondary role of seed weight in yield determination. Importantly, the association in Fig. 2A reinforces the notion that yield residuals are physiologically meaningful. If heat stress contributed to departures from the general relationship yield vs

PTQvpd, we could expect, but did not find, correlation between yield residuals and maximum temperature during the critical period (Fig. 3B). However, PTQvpd already incorporates maximum temperature in the calculation of vapour pressure deficit. In contrast, residuals of the relationship between yield and PTQ declined with increasing maximum temperature (Fig. 3C).

The expected decline in yield with late sowing was verified (Fig. 3D) but seasonal and sowing date effects disappeared after accounting for PTQvpd (Fig. 3E). The average residuals of the relationship between yield and PTQvpd differed among varieties with ICC5912 showing negative residuals indicating lower yield at the same PTQvpd (Fig. 3F). Seed weight declined with increasing minimum temperature during grain fill and was unrelated to maximum temperature in this period.

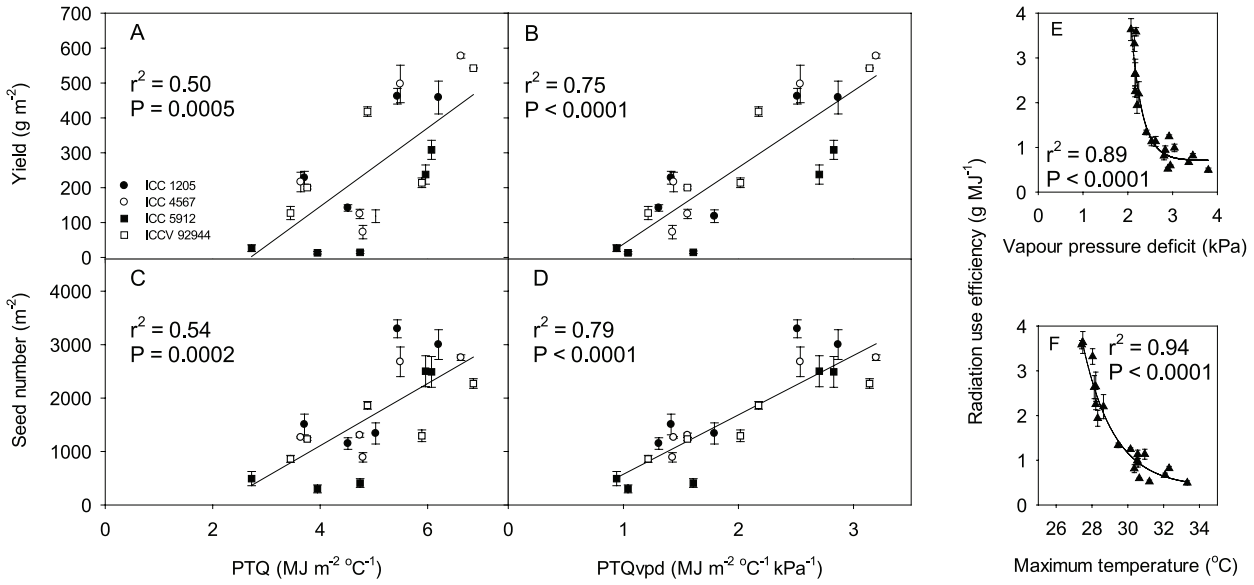

Figure 2 (A-D) Yield and seed number of chickpea crops as a function of photothermal quotient PTQ and photothermal quotient corrected for vapour pressure deficit PTQvpd. Each point is a cultivar, according to key in A, grown under five environmental conditions resulting from combination of seasons and sowing dates. Lines are model II regressions (reduced major axis). Relationship between crop radiation use efficiency and (E) vapour pressure deficit and (F) maximum temperature for the pooled data set; each point is a combination of variety and season/sowing date. Error bars are two standard errors of the mean.

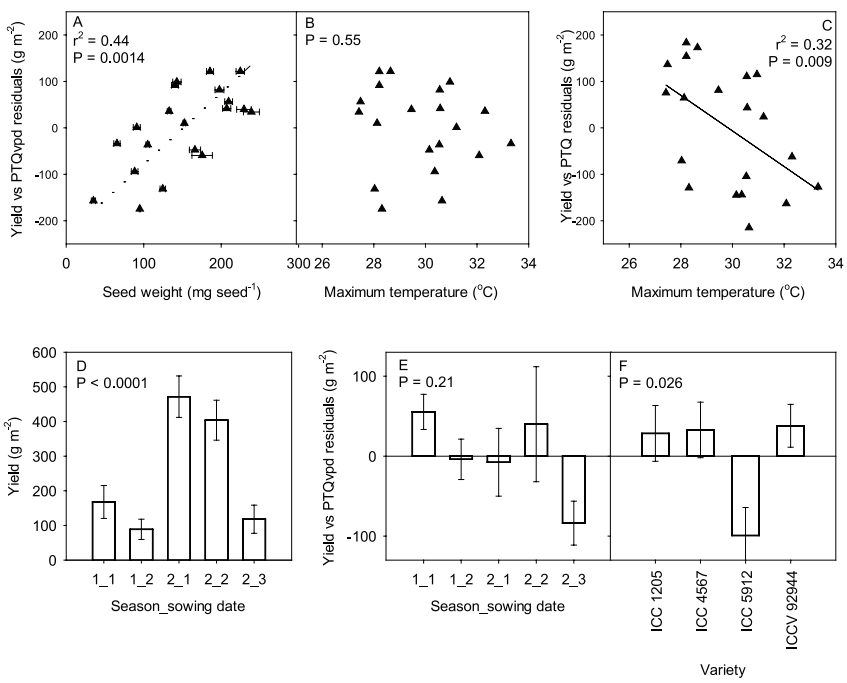

Figure 3. Residuals of the relationship yield vs PTQvpd in chickpea crops grown in five environments as a function of (A) seed weight and (B) maximum temperature during the critical period. (C) Residuals of the relationship yield vs PTQ as a function of maximum temperature during the critical period. (D) Yield and (E) average residuals of the relationship yield vs PTQvpd in five environments defined from combination of season and sowing date. (F) Average residuals of the relationship yield vs PTQvpd of four varieties. Data are pooled across varieties (D,E) or environments (F). In (A) the dashed line is model II regression (reduced major axis) and in (C) the solid line is model I regression (least squares). Error bars are two standard errors of the mean.

Conclusion

Crop adaptation to non-stressful, developmental thermal effects and stressful temperature disrupting reproduction involve different physiological processes and requires different agronomic and breeding solutions. Our analytical approach partially separates these effects on the basis of strong physiological principles, adds value to sowing date trials, and is likely to return more meaningful rankings of varieties. This approach could also be used to test the adaptive value of agronomic practices.

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Heat shock response in wheat under Free Air CO_2 Enrichment

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Abstract
Heat waves have the potential to significantly reduce grain production and quality of rain-fed cropping systems. Along with expected increases in global atmospheric CO_2 concentration and average ambient temperature, due to climate change, there will also be an increase in the frequency of heat waves combined with increasingly severe terminal drought for many arable regions. In the development of adaptive management strategies, simulation modelling provides a potentially powerful tool to investigate the effects of climate and weather variables on wheat production. Many contemporary models used throughout the world do not adequately account for heat shock response of wheat during the reproductive and grain filling phase and data supporting the development of detailed heat shock modules is valuable, particularly under varying CO_2 environments. For the current study, two wheat varieties (cv. Scout & Yitpi) were exposed to heat stress (36 to 38 °C over 3 consecutive days) at two growth stages around anthesis with atmospheric CO_2 concentrations of 385 and 550 ppm using Free Air CO_2 Enrichment (FACE). Elevating CO_2 increased average yield by 31% which was attributed to a significant increase in grain number (27%). Kernel size also increased by 7% across both cultivars, although this was only significant for cv. Scout. Heat applied five days prior to anthesis caused grain number to decline by 0.21% per °C.hr (>32°C) for cv. Scout, which translated to a yield decrease of 0.22% per °C.hr (>32°C). For cv. Yitpi, there was no effect of pre-anthesis heat on yield components, although there was a consistent trend of increasing kernel size across both cultivars. When heat stress occurred 15 days after anthesis, grain number was unaffected for either cultivar; however, there was a consistent, non-significant trend of decreased kernel size. No interaction of heat and CO_2 concentration were observed. Crop canopy temperature (screen) was equivalent across ambient and elevated CO2 conditions; however, spike temperature was 1°C cooler under eCO_2. The screen temperature of the canopy compared to the 1.2 m standard (BoM), the canopy temperature was constantly 1°C hotter, which has implications for phenology prediction within crop models. The current work contributes to our experimental understanding of the effects of heat shock to wheat growth under different CO_2 growing conditions and supports the development of robust heat shock modules for incorporation into crop models.

Keywords
Crop models, heat shock, FACE, AGFACE, terminal drought

Introduction
For field crops grown in Mediterranean-type environments, heat waves have the potential to significantly reduce grain quality and production. Higher global atmospheric CO_2 concentrations are anticipated and in many semi-arid regions such as southern Australia this will lead to reduced growing season rainfall and increases in the frequency of heat waves (IPCC, 2012). Wheat is considered most sensitive to sudden heat stress (above 31ºC) if it occurs during the reproductive and grain-filling phase (Wardlaw and Wrigley, 1994). For example, yield was reduced by 18-35% for 35ºC heat stress imposed over a single day (Talukder et al., 2010). To investigate the effects of future climate and weather variables on wheat production and to aid the development of adaptive management strategies, simulation modelling provides a powerful tool for resolving these dilemmas (Jamieson and Semenov, 2000). Currently, few crop models comprehensively account for the response of wheat to extreme heat during the reproductive and grain filling phase (Barlow et al., 2014) which highlights the need for algorithms which describe the crop response to extreme heat events (Zheng et al., 2012). In the development of such algorithms, the generation of data defining wheat response to heat shock, particular under elevated atmospheric CO_2 is warranted. This paper reports on the response of heat shock under elevated CO_2 conditions to develop heat shock algorithms for incorporation into contemporary crop simulation models.

Methods
Heat chambers were used to examine the impact of simulated heat waves on wheat production and were applied at one of two stages (five days pre- and 15 days post-anthesis) for wheat grown at the Australian

Grains Free Air CO_2 Enrichment (AGFACE) experiment in Horsham, Australia (Mollah et al., 2009) during 2014. The AGFACE experiment comprised two atmospheric daytime CO_2 levels (ambient, 385 and elevated, 550 ppm). Prior to sowing 34 mm was applied to experimental plots. Between sowing (29 May 2014) and anthesis (07 Oct 2014) there was 94 mm rainfall and 59 mm of supplemental irrigation and in the post-anthesis phase up to harvest (19 Nov 2014) 1 mm rainfall and 60 mm of irrigation. For the heat shock treatments, target temperature was 38°C in the crop canopy, applied for 6 to 8 hours and thereafter reduced to ambient temperature during the night time over three days. Heat chambers consisted of right-angle hollow section (RHS) frame boxes (1200mmW×800mmD×500mmH) that were clad with Sun Tuff Greca Laserlite®. Electric fan heaters (1200W) were mounted at the top of the chambers with the temperature controlled by a thermocouple situated in the crop canopy. Mixing of outside air was allowed from the base of the chamber. For monitoring temperature, screens were erected at canopy and 1.2 m within ambient and elevated CO_2 treatments and temperature was logged at five minute intervals using a combination of TinyTag Ultra 2 sensors, TGU-4017 (temperature) and TGU-4500 (temperature and relative humidity). For spike temperature, thermocouples were attached to the glume of main spikes, mid-head on the southern side.

Results and Discussion

Heat chamber performance

The performance of the heat chambers in elevating canopy temperature of wheat is presented in Fig 1. For the pre-anthesis heat treatment, average temperature across the three days (6 hours per day) was 36°C, compared with an average ambient air temperature of 20°C for the same period. For the post-anthesis heating, average canopy temperature was 38°C and the ambient air temperature for this period was 31°C. Variation in chamber performance between the pre- and post-anthesis heat treatments, where higher peak temperatures were achieved during the post-anthesis heat treatment may be due to several factors: a) the greater latent heat associated with the relative lush state of the crop canopy during the pre-anthesis phase; and b) cooler ambient air conditions in the pre-anthesis phase limiting the heating capacity of the chambers. For the design of heat chamber used, the concentration of CO_2 within the heat chamber positioned in the FACE ring is equivalent to free air eCO_2 environment (Nuttall et al., 2012). Relative humidity of the ambient air during the pre-anthesis phase was between 30 & 55% over the three day whereas within the heat chambers this decreased to circa 28%. During the post-anthesis heat treatment the relative humidity of the ambient air and heat chamber were similar, between 20 & 30%.

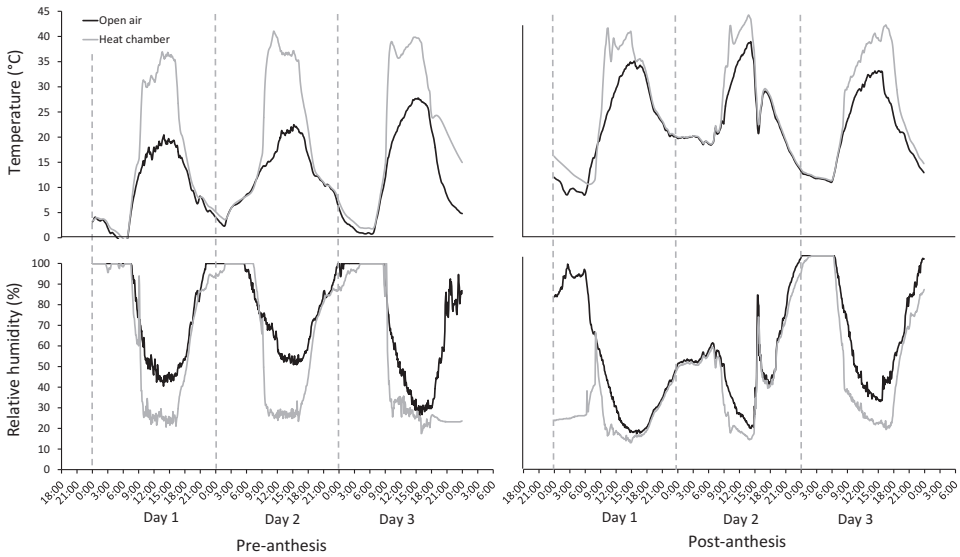

Figure 1. Crop canopy temperature and relative humidity for open air and heat chambers during the application of heat shock to wheat. Heat (target 38°C) was applied at two growth stages (5 days pre- and 15 days post-anthesis) for six hours per day over three consecutive days. Pre-anthesis heat was applied from 01 Oct 2014 to 03 Oct 2014 and post-anthesis heat applied from 21 Oct 2014 to 23 Oct 2014.

Wheat growth

Elevated CO_2 significantly increased yield by 29 and 44% for Scout and Yitpi respectively (Table 1). The increase in yield was due to large and significant increases in grain number of 22 and 32% for Scout and Yitpi respectively under eCO_2. For both cultivars grown under eCO_2, kernel size increased by 7%, although this increase was only significant for cv. Scout.

For heat shock there was a significant difference between cultivar response. For cv. Scout, heat applied five days prior to anthesis reduced grain number and grain yield by 18% while kernel size did not change significantly. When Scout was exposed to heat shock 15 days after anthesis, there was a significant reduction in yield of 14%, although yield components did not change significantly In contrast, for cv. Yitpi, heat at either stage had no significant impact on crop yield components, although for post-anthesis heat stress kernel size was reduced by 9% (non-significant). The limited response of Yitpi may be due to delayed development (4 days) compared with Scout. Of note is that there was no interaction between CO_2 level and the heat shock response in terms of overall yield and yield components for either of the cultivars.

Table 1. The response of wheat to FACE and heat shock. The yield components of two cultivars, Scout and Yitpi are presented.

		Scout				Yitpi			
		Grain no. (grains/m2)	**Kernel size (mg/1000)**	**Yield (t/ha)**	**HI**	**Grain no. (grains/m2)**	**Kernel size (mg/1000)**	**Yield (t/ha)**	**HI**
CO2	**Ambient**	4849	35.6	1.7	0.35	4936	34.3	1.6	0.35
	Elevated	5924	38.2	2.2	0.35	6498	36.8	2.3	0.31
	lsd (P<0.05)	360	1.9	0.2	ns	1169	ns	0.5	ns
Heat	**Ambient**	5867	37.1	2.2	0.37	5829	35.8	2.0	0.35
	Pre-anthesis	4826	38.3	1.8	0.35	5326	38.3	2.0	0.33
	Post anthesis	5465	35.2	1.9	0.35	5997	32.5	1.9	0.30
	lsd (P<0.05)	440	2.3	0.2	ns	ns	4.2	ns	ns

Heat load and crop response

For the pre- and post-anthesis heat treatments the corresponding heat load applied to crops (above 32°C) was 68 and 118°C.hr. In contrast, the open-air conditions over the same period were 0 and 13 °C.hr respectively. With regard to crop response of wheat (cv. Scout) to heat shock, this equated to a 0.21% reduction in grain number per C.hr (above 32°C), when heat stress occurred five days pre-anthesis. When heat stress occurred 15 days after anthesis the impact on grain number was limited (non-significant) to a 0.06% reduction per C.hr (above 32°C), and kernel size also decreased 0.04% per C.hr (above 32°C). Overall, pre- and post-anthesis heat shock reduced the yield of cv. Scout by 0.22 and 0.16% per C.hr (above 32°C) respectively. For cv. Yitpi, no significant reduction in grain number or yield due to heat treatment was observed, although a substantial (non-significant) reduction in kernel size due to post-anthesis heat equated to a 0.08% reduction in grain weight per C.hr (above 32°C).

FACE and screen position effect on apparent temperature

For crops grown under contrasting CO_2 concentration at ambient temperature, canopy temperature measured within a screen was equivalent at both five days pre- and 15 days post-anthesis (Fig 2 a) with no deviation from the 1:1 line between ambient and elevated CO_2 environments. While spike temperatures, were on average 1°C cooler where crops were growing under high CO_2 conditions. This is contrary to expectations where the reduced transpiration of high CO_2 crops may translate to a hotter canopy. These results may reflect larger crop canopies and greater leaf area with eCO_2 condition resulting in greater net cooling with post-anthesis irrigation ensuring sufficient water to maintain adequate transpiration. There may also be more available soil water later in the season under eCO_2 crops (Leakey et al., 2009).

The temperature at the crop canopy (within a screen) compared with screen temperature at 1.2m above the soil surface was consistently 1oC hotter at the crop canopy, this pattern being consistent both at five days pre- and 15 days post-anthesis (Fig 2 *b*). Such variation in apparent temperature has implications for the application of BoM derived temperature data for driving wheat phenology within crop models where canopy temperature is not explicitly calculated. If consistent rules can be established between measured BoM screen temperature data and crop canopy temperature, this will assist in improving simulated phenology of crop models.

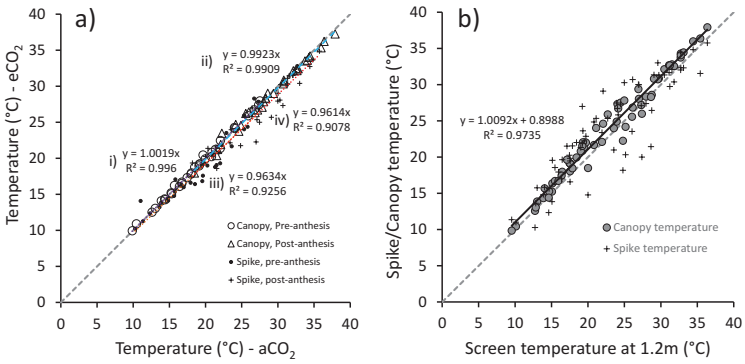

Figure 2 a) Comparison of wheat canopy and spike temperature for crops grown under ambient and elevated CO_2 conditions. Regression functions i, ii, iii and iv describe pre-anthesis canopy, post-anthesis canopy, pre-anthesis spike and post-anthesis spike temperatures respectively, b) Comparison of screen temperature measured at 1.2 m, wheat canopy and wheat spike. Temperature data are for three consecutive days, 5 days pre- and 15 days post-anthesis, expressed as hourly means of temperature recorded at 5 minute intervals between 0800 and 1800H. Regression function describes screen and crop canopy temperature. Broken line is 1:1.

Conclusions

The current study provides response data of wheat to heat shock under contrasting CO_2 conditions and compares crop canopy temperatures across CO_2 and height factors. Typically pre-anthesis heat shock limited yield potential through grain number reduction, with a tendency for some compensation in kernel size where grain number is reduced. For post-anthesis heat stress, the reduction in kernel size limited yield. For CO_2 interaction with heat stress, next steps require a meta-analysis over different seasons to verify these single year observations. Overall, such data help support the development of algorithms for use in crop models which have the broader utility for developing adaptive management strategies for maintaining yield and quality of wheat production amid the impacts of climate change.

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Heat stress effects on grain sorghum productivity-biology and modelling

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Abstract
Heat stress can cause sterility in sorghum and the anticipated increased frequency of high temperature events implies increasing risk to sorghum productivity in Australia. Here we summarise our research on specific varietal attributes associated with heat stress tolerance in sorghum and evaluate how they might affect yield outcomes in production environments by a crop simulation analysis. We have recently conducted a range of controlled environment and field experiments to study the physiology and genetics of high temperature effects on growth and development of sorghum. Sorghum seed set was reduced by high temperature effects (>36-38°C) on pollen germination around flowering, but genotypes differed in their tolerance to high temperature stress. Effects were quantified in a manner that enabled their incorporation into the APSIM sorghum crop model. Simulation analysis indicated that risk of high temperature damage and yield loss depended on sowing date, and variety. While climate trends will exacerbate high temperature effects, avoidance by crop management and genetic tolerance seems possible.

Key words
Climate change, sorghum, pollen germination, seed set

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a major summer crop in dryland farming system in NE Australia, where grain yield can be negatively affected by high temperature stress. The maximum temperature in sorghum growing areas will exceed 32°C in summer months (Muchow et al. 1994) under future climate change scenarios (IPCC 2007). As a consequence, the frequency of high temperature occurrences is likely to increase. However, to date no environment characterisation of the incidence of high temperature stress in the Australian sorghum belt has been conducted and therefore effects of high temperature stress on sorghum grain yield have not been quantified.

Sorghum is most sensitive to high temperature stress around the reproductive development stage (Prasad et al. 2008; Nguyen et al. 2013; Singh et al. 2015;), although high temperatures can also affect plant height (Prasad et al. 2008; Nguyen et al. 2013), leaf growth, and phenology (Hammer et al. 2010). Importantly, significant genotypic variation in seed set response to high temperature has been observed for sorghum, both in the threshold temperature and in the tolerance to high temperatures above the threshold (Singh et al. 2015). These differences in threshold temperature around anthesis are likely to cause complex genotype by location interactions for grain yield.

The superiority of specific genotype and management combinations can vary from year to year depending on prevalent environmental conditions. Therefore, quantification of the effects of high temperature on grain yield of sorghum requires an integration of genotypic variation in tolerance to high temperatures with spatial and temporal variation in the incidence of high temperature occurrence. Crop growth simulation modelling can provide such integration. The APSIM suite of models provides a suitable platform to incorporate novel scientific knowledge on the physiology of crop growth and development (Hammer et al. 2010) into crop models, which can be combined with historical climate records to simulate the effects on crop productivity under high temperatures of changes in genetics (G), environment (E), and management (M) – the G*E*M landscape. Hence, the aims of this research were to (1) quantify genotypic differences in the response of seed set to high temperature stress, and (2) assess effects of these differences on production risks of sorghum, using long-term simulations for grain yield at Moree in the sorghum belt of Eastern Australia as an example.

Experiments

Genetic material

A diverse set of 20 sorghum genotypes, provided by the DAF/UQ sorghum breeding program, was used in the experiments. The material included parents of mapping populations, and elite lines that are parents of hybrids used in the sorghum breeding program.

Growing conditions

To quantify the physiology and genetics of high temperature effects on sorghum, experiments were conducted in controlled growth chambers at St Lucia, and in the field at Gatton, Queensland. In the first controlled environment experiment, 20 diverse sorghum genotypes were grown through to maturity at four day/night temperature ranging from 30/22°C (optimum temp - OT) to 38/22°C (high temperature - HT) without water limitation. In the second controlled environment experiment, that aimed to identify the development stage that is most sensitive to high temperature stress, plants of tolerant and susceptible genotypes were grown either at OT or HT, and then transferred between chambers at 5 day intervals starting just after flag leaf emergence. The field experiment was conducted on contrasting lines, selected from the controlled environment experiments, to validate in the field the effects observed in the controlled environments. Plants were grown either with or without specifically designed covers that raised daytime maximum temperature by about 6°C.

Observations

Pollen germination was measured using an *in vitro* pollen germination method (Nguyen et al. 2013). Panicles were harvested at physiological maturity and seed set percentage was measured (Nguyen et al. 2013).

Results

Reproductive development stage most sensitive to increased temperature

The 20 sorghum genotypes differed in the threshold at which temperature can affect seed set percentage (34-36˚C) and in the tolerance (low-high) to high temperature stress above that threshold. Temperature effects on seed set percentage were consistent between the field and control environment facility (Singh et al. 2015).
In the transfer experiment, a transfer of five days from OT to HT or from HT to OT had no effect on seed set percentage if the transfer occurred at 18 leaf stage, at flag leaf stage, or at 20 days after flag leaf stage (Fig. 1). However, the effect of transfer was greatest if the transfer occurred at 10 days after the flag leaf stage, suggesting that the 10-15 day period just before and around anthesis is the period most sensitive to high temperature stress.

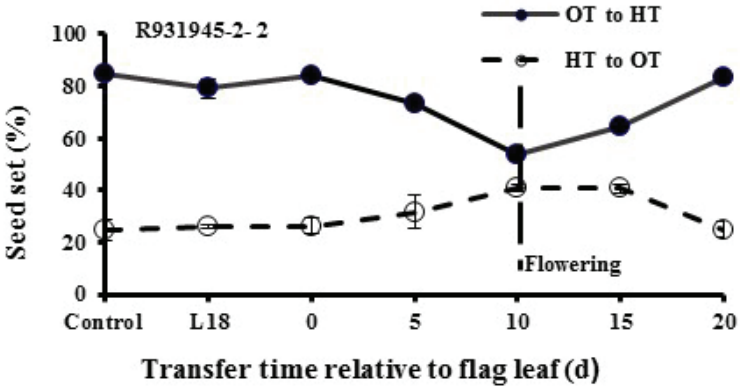

Fig. 1. Effect on seed set percentage of transferring plants of genotype R931945-2-2 from 31/21°C (OT) to 38/21°C (HT) (●___●) and from HT to OT (o----o) for five days at leaf 18, flag leaf (0), 5 days after flag leaf (DAFL), 10 DAFL, 15 DAFL, and 20 DAFL. The control plants were grown continuously in either OT or HT. Error bars indicate the standard error of the mean for each transfer. Vertical dotted line indicates approximate time of anthesis.

Simulating production risks associated with high temperature effects on grain yield

In order to quantify production risks, long term simulations were conducted using 59 years of weather data for Moree (NSW). Implementation of the effect of high temperature stress on seed set percentage, and hence grain yield, was based on the results of the controlled environment experiments. Five hypothetical genotypes were used in the simulations, where the first genotype was completely tolerant to high temperature and the other four represented a factorial design with two thresholds and two levels of tolerance (Fig. 2).

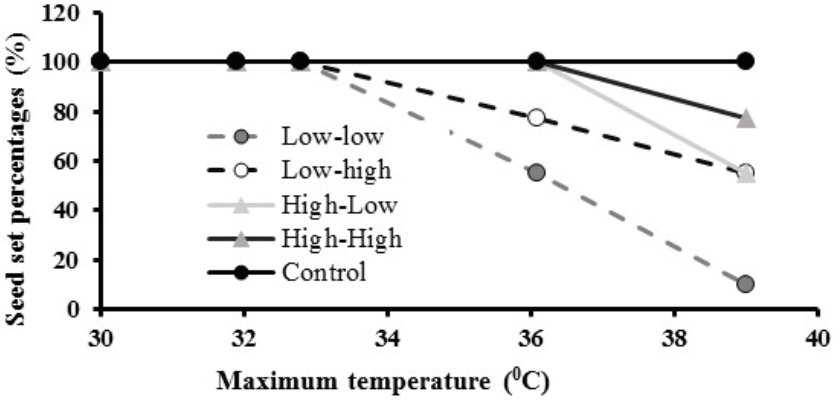

Fig. 2. Seed set percentage versus maximum temperature for five hypothetical genotypes that differ in either the threshold (high vs Low) and tolerance (high vs low) of seed set response to high temperature.

The effects of high temperature on simulated grain yield for each year at Moree are shown in Fig.3. A sowing date of 1 October was used every year, as this resulted in a high probability of occurrence of high temperature stress around flowering. Yield of two genotypes with either low or high threshold and tolerance is expressed relative to that of a control genotype that is not affected by high temperatures. The simulated yield reduction varied considerably across years for the heat sensitive genotype (L-L) and in many years the yield reduction exceeded 10%. In contrast, grain yield of the heat tolerant genotype (H-H) was rarely affected by high temperature stress (Fig. 3).

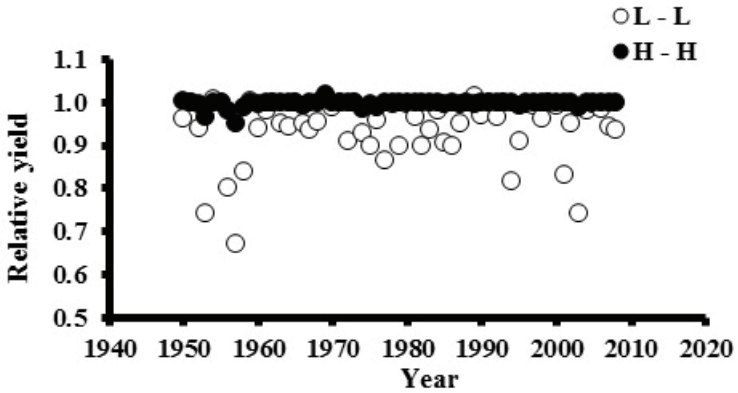

Fig. 3. Simulated grain yield of sorghum genotypes with either high threshold and high tolerance for high temperature stress (H-H) or low threshold and low tolerance (L-L), relative to yield of a control genotype that is not affected by high temperature stress at Moree for a period of 59 years following sowing in October.

Consistent with the large year effect on relative grain yield for the sensitive genotype (Fig. 3), the effect of variation in sowing date on grain yield was also greatest for the sensitive genotype (L-L, Fig. 4). The average yield loss associated with high temperature effects for genotype (L-L) was greatest for sowings from October to December, whereas sowing in early September or late December had lower risks of excessive yield reductions. In contrast, genotype (H-H) never experienced yield reductions greater than 10%. The results thus suggest that while it is plausible to reduce high temperature risks through changing sowing dates, the introduction of genetic tolerance would be a more effective strategy.

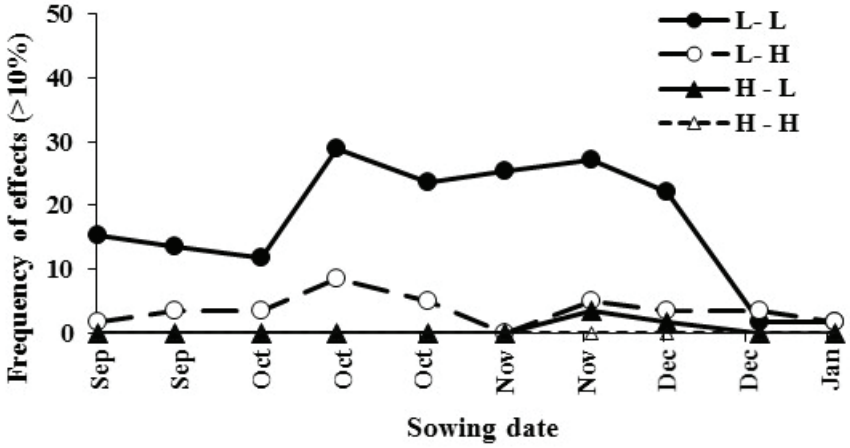

Fig. 4. Probability of yield loss exceeding 10% compared to the control genotypes for four hypothetical genotypes for a range of sowing dates at Moree. Genotypes differed in the threshold or tolerance to high temperature above the threshold: L-L low threshold, low tolerance; L-H low threshold, high tolerance; H-L high threshold, low tolerance; H-H high threshold, high tolerance.

Conclusion

The frequency and severity of high temperature events are predicted to increase over the next decade (IPCC 2007) and this will likely exacerbate the adverse effects of high temperature stress on crop yields. It is clear that risks of yield reduction of sorghum due to high temperature effects will increase. Recent research suggests that there is genotypic variation for tolerance among sorghum genotypes and that a period of 10-15 days around flowering is the period most sensitive to high temperature stress. Simulation studies suggest that management of sowing date can somewhat reduce the adverse effects of high temperature on grain yield, but this is less effective in moderating high temperature risks than genetic improvement. The presence of potential sources of genetic tolerance to high temperature effects make genetic improvement a suitable avenue to mitigate long-term effects of climate change on sorghum productivity in eastern Australia.

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Genetic variation in wheat pollen heat tolerance

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Abstract
Cereal crops will be exposed to heat waves more frequently in the future according to climate forecasts. When these periods of elevated temperature coincide with sensitive stages of reproductive development in wheat (*Triticum aestivum*) major yield loss often occurs. This investigation tested the hypothesis that there is genetic variation in pollen heat tolerance during the meiosis and anthesis stages of development in wheat. Studies were conducted on five genotypes in controlled environment greenhouse experiments in Sydney and Narrabri. Wheat genotypes were exposed to high temperature stress (35/22oC day/night) for 3 days at meiosis and anthesis and their response compared with unheated controls. Kernel weight per spike, kernel number per spike and 1000-kernel weight were measured as indicators of the heat stress response on pollen traits and grain yield. Crusader was the most sensitive to high temperatures during reproduction, while Sokoll performed best under heat stress, experiencing little reduction in kernel number and weight per spike. Traits contributing to grain yield were most reduced when heat stress coincided with anthesis rather than meiosis. High temperature stress caused abnormalities in the progression through meiosis, including arrested pollen development. The reduction in grain yield in greenhouse plants exposed to high temperature stress at anthesis provided similar trends to wheat grown under field conditions in Narrabri. This new information on the heat stress response of wheat at meiosis and anthesis could be exploited to develop varieties with superior reproductive stage heat tolerance for future warming and variable climates.

Key words
Wheat, heat, pollen, meiosis, anthesis, breeding

Introduction

Hotter and drier climate conditions anticipated in southern and western regions of Australia are predicted to reduce wheat yield by up to 15% (Kokic *et al*. 2005). Short duration heat shock, when maximum temperatures can exceed 35°C, are already quite common in the grain belt of Australia during spring when crops are approaching flowering. Pollen development has been identified as the most heat-sensitive process in plant sexual reproduction, with both meiosis and gametogenesis being thermosensitive (Bokszczanin and Fragkostefanakis 2013). Various degrees of tolerance to high temperatures (36/30°C) at anthesis were reported in wild wheats (*Aegilops* species) (Pradhan *et al*. 2012). Although previous research has identified wheat germplasm with superior heat tolerance during anthesis, few studies targeted the sensitive pollen development stage (e.g. meiosis). This study aims to test the hypothesis that there is genetic variation in pollen heat tolerance during meiosis and anthesis in wheat.

Materials and methods

Five wheat genotypes (Table 1) were grown at the Darlington polytunnel, the University of Sydney, Sydney and also repeated in a greenhouse at Narrabri in northern NSW. Five seeds per genotype per pot were sown across three temperature different treatments with four replicates in a completely randomised block design. Plants were heated (35˚C/22˚C day/night) for three days at either meiosis or anthesis and compared with an untreated control.

Table 1. List of varieties/lines, their pedigree and pre-determined tolerance or sensitivity to high temperature based on field experiments in Narrabri (*CIMMYT- International Maize and Wheat Improvement Centre)

Variety	Heat tolerance	Pedigree / Accession
Sokoll	Tolerant	Synthetic wheat derivative
WH542	Tolerant	CIMMYT* breeding line released as a variety in India
Atilla*2/PBW65	Sensitive	CIMMYT breeding line Atilla x PBW65 (Indian variety)
Berkut	Sensitive	CIMMYT Drought tolerant breeding line
Crusader	Sensitive	Pedigree Sunbrook/H45 LongReach Plant Breeders cultivar released in NSW

Temperature and relative humidity were controlled in the greenhouse facility before and after the imposition of heat treatments. Temperature was set at 23/15oC day/night with 50% humidity. Auricle distance was monitored once flag leaf emergence occurred in each plant. This is the distance measured between the auricle of the flag leaf and the auricle of the penultimate leaf (Fig. 1). An auricle distance of 4-8 cm was used as a morphological marker for meiosis (Barton *et al.* 2014).

Fig. 1. Auricle distance (cm): the distance (cm) between the auricle of the flag leaf and the auricle of the penultimate leaf.

Individual primary culms at the appropriate developmental stage for the heat treatment were tagged for later identification. Plants were transferred to growth cabinets, when the majority of culms in each pot had reached either meiosis or anthesis and exposed to high temperature for 3 days. Control plants remained in the greenhouse during this period under controlled temperatures (23/15˚C day/night). Pots were returned to the greenhouse to mature following heat treatment. At physiological maturity, tagged culms were randomly selected from each pot and the spikes were removed. The grains from each spike were collected using a single head thresher and bagged separately. The kernel weight and number per spike and 1000-kernel weight was recorded for each pot. The percentage reduction in grain weight per spike was calculated for each variety in this experiment and compared with the percentage reduction in grain yield of those same genotypes evaluated in a late sowing field study at Narrabri in 2012 to determine the relationship between controlled environment and field screening. The field experiment was conducted in 2012 at the International Grains Research Centre in Narrabri using early (13 May 2012) and late (15 August 2012) sowings to compare the response to high temperature stress between genotypes. Statistical analysis was conducted by analysis of variance (ANOVA) for each character measured using Genstat 16th Ed.

Results and discussion

There was a general consistency in the ranking of genotypes for heat stress tolerance across the greenhouse studies in Sydney and Narrabri, although only the Sydney data is presented in this paper. All genotypes subjected to high temperature stress expressed a significant reduction in mean kernel number per spike and kernel weight per spike, compared with the control ($P<0.01$) (Fig. 1). Anthesis was the stage of development most sensitive to high temperature stress. Average kernel weight per spike reduced by 55% when heat stress occurred at anthesis compared with 47% at meiosis. Crusader was the exception and temperature stress at meiosis had greater influence on kernel traits. The interaction between variety and treatment was significant

for all traits ($P<0.01$), indicating that genotypes responded differently to high temperature stress applied at different development stages. The greatest difference in heat stress response, based on kernel number and weight per spike, was observed between Crusader and Sokoll. The heat sensitive cultivar Crusader had the most negative response of all genotypes to high temperature at both meiosis and anthesis. Heat stress reduced kernel weight up to 89% and greatly reduced kernel number per spike. In contrast, heat stress only slightly reduced kernel number and kernel weight per spike at meiosis in Sokoll. Of all varieties tested, Sokoll was most resilient to high temperature stress during the reproductive stages. Berkut also demonstrated some tolerance to heat stress. However, despite WH542 being classified as tolerant to high temperatures, a significant difference in kernel weight per spike between heated (meiosis= 1.38 g, anthesis= 1.41 g) and unheated controls (2.96 g) was observed. The effect of heat treatment on 1000-kernel weight was minor, but was most significant in sensitive genotypes. Highest 1000-kernel weight occurred in Attila*2/PBW65 heated at meiosis (62.7 g) and the lowest occurred in Crusader heated at anthesis (35.7 g). Heat stress at meiosis resulted in the highest 1000-kernel weight across treatments in most genotypes. Berkut was the only exception, recording higher 1000-kernel weight in the unheated control.

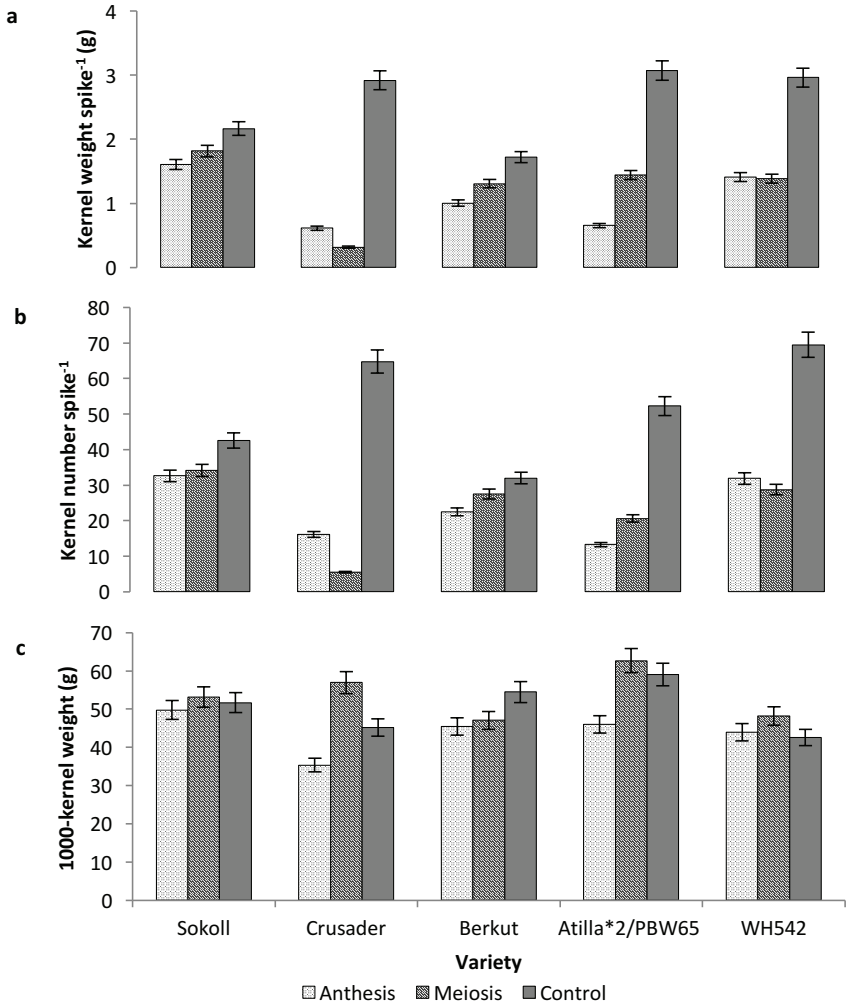

Figure 2. (a) Kernel weight per spike (g), (b) kernel number per spike and (c) 1000-kernel weight (g) of five varieties (Sokoll, Crusader, Berkut, Atilla*2/PBW65 and WH542) heated at meiosis and, anthesis (35˚/22˚C day/night for 3 days) and unheated control (Dots= anthesis, hashed= meiosis and solid= control). Error bars represent standard error of the mean.

A strong positive correlation (r=0.89) was found between kernel number per spike and kernel weight per spike ($y = 0.0464x + 0.1032$). This relationship was strongest in plants that were heated at either meiosis or anthesis compared with the unheated control. 1000-kernel weight did not appear to have any impact on kernel weight per spike. Grain yield loss of the same five genotypes evaluated in late sown heat stress treatments in field experiments at Narrabri in 2012 correlated (r=0.76) with the reduction in kernel weight

per spike in the polytunnel study (Fig. 3). Yield loss was calculated as the difference between optimally sown (13 May) and late sown (15 August) materials. The ranking of wheat genotypes for heat stress tolerance was consistent under field and polytunnel conditions; Crusader was the most sensitive and Sokoll was the most tolerant to high temperatures during the reproductive stage.

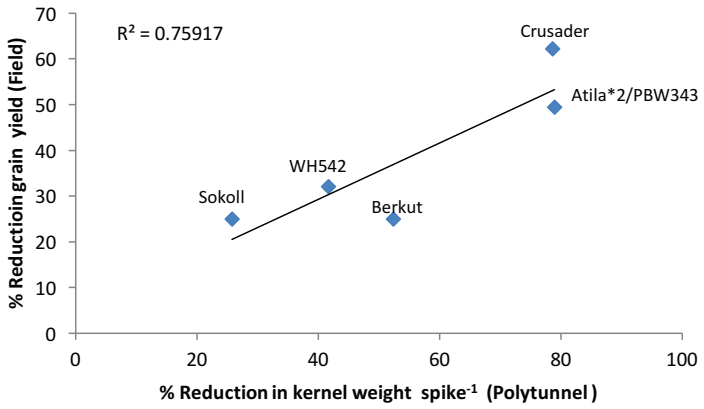

Figure 3. The relationship in average percentage reduction in grain yield between wheat grown in the polytunnel under high temperature stress at anthesis compared with unheated control and late sown compared with early sown wheat under field conditions in Narrabri for five wheat genotypes (Sokoll, WH542, Berkut, ATILLA*2/PBW343 and Crusader).

Sokoll was classified as the most heat tolerant genotype as no significant grain reduction occurred when exposed to high temperature at both anthesis and meiosis. This genotype is a synthetic derived line containing new D-genome diversity from *Aegilops tauschii* that may have been lost during the evolution of wheat or never present in the original 'chance' cross between ancestral tetraploid wheat and the D genome donor, which occurred some 8,000 years ago. Sokoll is therefore a genetic resource for pollen heat tolerance that can be used to develop more heat tolerant wheat cultivars. Kernel number per spike under temperature stress could be an effective selection criterion for crop improvement. As most of the variation in heat tolerance is additive, the breeder can identify the least related lines from among the best performing materials under heat stress to combine in crossing (Trethowan *et al*. 2010).

Conclusions

This study supports the hypothesis that there is genetic variation in pollen heat tolerance during meiosis and anthesis in wheat. Vulnerability to high temperature stress is heightened at anthesis for some genotypes and at meiosis in others, such as Crusader.

Acknowledgement

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South East Australian grain growers and advisors rate grain filling heat as a greater risk than frost

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Key words
Modelling, survey

Abstract
DEDJTR undertook an email survey in November 2013 to understand the current perceptions of the grains industry to management and impacts of climate volatility on crop production. The 111 responses were widespread throughout the grain growing areas of south-eastern Australia, with Victoria and the NSW Riverina predominating. The majority of grower responses came from those operating larger farms. For cereal crops, 68% and 77% of respondents were either moderately or very concerned about frost damage at flowering or heat stress damage during grain filling, respectively. For the median of participants, frost damage was perceived to happen two to three times a decade, and four out of ten years for heat shock. The overwhelming response (60%) was that heat stress was perceived to have the greatest effect on cereal crop yield than frost. Data was also collected for pulses and canola. Mitigation techniques favoured for frost damage to crops were, either sowing a mix of crop types and/or manipulating maturity time through crop/cultivar choice. Growers rarely delayed sowing to avoid the frost window. Mitigation techniques favoured for heat shock to crops were by sowing early and/or sowing a range of crop types. Growers generally did not sow early maturing crops. This survey provides a valuable snapshot of industry knowledge and perceptions around the impacts of extreme heat and frost, as well as the potential mitigation techniques being used; with the results being used to inform crop modelling and extension activities.

Introduction

Crop production across Australia is being increasingly impacted by a changing climate and highly variable weather as the average annual daily mean temperatures have increased progressively since the middle of the 20th century against a backdrop of natural year to year variability (CSIRO and Bureau of Meteorology 2012). One of the key challenge for crop production is the change in climate extremes, both the increased frequency of very hot (>40°C) daytime temperatures since the 1990's (CSIRO and Bureau of Meteorology 2012) and the increased incidence of frost across the Australian grain belt between 1960 and 2011 (GRDC Groundcover November 2012). Extreme weather events, such as frost and heat shock (short period of very high temperatures (>33°C)), are reducing crop production and represent a substantial challenge to the Australian grain industry. We conducted a survey of farmers and their advisors to gauge their perceptions of these issues and how they were managing it.

Methods

A web survey (SurveyMonkey) was used in the collection of data to gauge the perception of the grains industry of the risk and relative impact of extreme temperature events on production. The survey was sent out to 1809 people and was open from mid-October to November 2013. The lists consisted of 1431 farmers, 326 agribusiness and 53 government agronomists. Initially the distribution list was sought from those growers and agro consultants of the DEDJTR's 'The Break' newsletter and subsequently expanded to include the GRDC's monthly information email list and also the Pritchard Agro consultant distribution list. Individual responses were identified by postcode allowing approximate spatial mapping of results.

Results and Discussion

Responses from 132 people were collected, of which 111 were sufficiently complete or legitimate survey responses. The majority of the respondents were growers (72%) and the remainder advisors. This reflects the ratio of farmers to advisors in the email distribution list, with a response rate of 8% for advisors and 6% for growers respectively. The regional location of respondents was widespread throughout the grain growing areas of south-eastern Australia, with responses from Victoria (69%) and the NSW Riverina (10%) predominating. When asked about perception of the incidence of frost damage in cereals, the response is wide ranging, but the median response of participants was that frost damage occurs two to three times every

decade (Figure 1). Five people reported they were unsure. No respondents thought their risk was at the extremes of never or all the time.

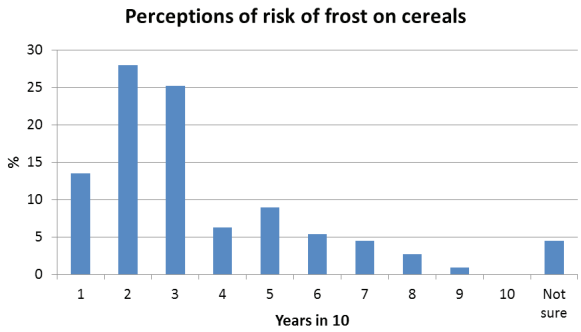

Figure 1. Respondents' perception of the likelihood of frost damage to wheat during the reproductive and grain filling phase (n = 111).

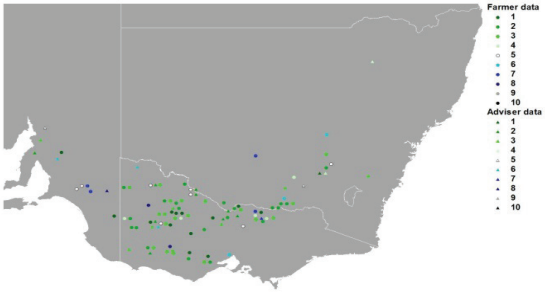

Figure 2. Geographic spread of responses to the number of years out of 10 that respondents think frost affects wheat near flowering.

When this data is spatially represented across south eastern Australia it shows that the perceived frequency of 1-to-3 years per decade occurs over most of the region, but also shows where the higher perceived risks exist (Figure 2). There appears to be no pattern except in the south east Mallee of South Australia where a cluster of growers believe they are affected quite often (>50% of years). DEDJTR modelling research shows that this area in the South Australia Mallee is a moderate frost risk when planting a mid-season variety on an autumn break of 25 mm rain (Barlow et al. 2013), however this modelling does not take into account the selection of sowing time and crop variety which may be aimed at avoiding warm dry conditions at the end of the grain-fill period. In contrast, while this modelling suggests that the west Wimmera of Victoria has a chance of frost around flowering in 40-70% of years, this frequency of risk was not reflected in the survey responses.

There appear to be a number of respondents who perceived a high frequency of frost risk randomly scattered through the study region (Figure 2). Some of these responses are in close proximity to those that perceived a much lower risk. While regional differences are an important consideration in understanding frost risk, differences in topography and management strategies within a region mean that it is possible that seriously affected farmers can farm close to people who have never been affected during their farming career. It's also likely that some farmers have a poor understanding of their historic frost risk.

When asked about the strategies used to mitigate against frost damage in cereals, most farmers and advisors used the selection of crop types and varieties with different maturities regularly (Table 1). Sowing time, a commonly recommended strategy to mitigate frost risk (Rebbeck and Knell 2007), either through delayed sowing or sowing across a mix of times, was not commonly used by respondents. Sowing at a mix of times was sometimes used and fewer people chose to sow later to reduce the risk of frost around flowering. This is not surprising, as there are known costs in terms of production from delayed sowing due to warmer drier conditions later in the season. The large number of respondents (59%) who never delay sowing suggests that growers are mainly considering the yield penalties from later sowing over the potential frost advantages. Interestingly some growers did treat their more frost prone areas differently or grow less of the susceptible crops. The number of respondents treating areas differently (19%) indicates a number of growers actively mitigating their frost risk in the known problem areas.

Table 1. The range of management option recommended or used by growers to mitigate against frost damage in cereals

	All the time	Most of the time	Some of the time	Never
Sowing a mix of crop types	26%	36%	28%	10%
Sowing a mix of crop maturities	20%	33%	37%	10%
Sowing at a mix of times	5%	16%	47%	32%
Delaying sowing	3%	2%	37%	58%
Treating frost prone areas differently	9%	10%	32%	49%
Grow less of the most susceptible crops	7%	13%	48%	32%

When asked about their perception of the risk of heat stress, the answer is very broad varying from 10-100% of years (Figure 3). DEDJTR modelling research shows there is a significant variation in the risk of heat shock during the grain filling period throughout the study region. When the modelling was conducted using a mid-season variety on an autumn break of 25mm rain, the years in which a heat shock event occurred during grain fill ranged from the 0-10% category up to 90-100% (Barlow et al. 2013).

The spatial assessment of these responses shows a greater level of uncertainty than for frost (Figure 4). Some respondents match the DEDJTR modelled analysis, but many exceptions exist where people's perceptions of heat risk are very different to their neighbours. Unlike frost risk, altitude and land aspect have much less influence on heat shock, so such large differences in incidence are unlikely to be real. There is clear evidence that people's perception of heat risk damage and yield penalty is not as clear as for that of frost, which is highly visual. Unlike frost, where damage is visible within a couple days to a couple weeks, heat damage may not be observed till harvest.

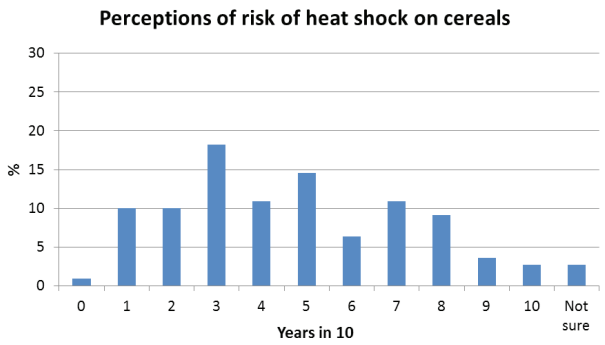

Figure 3. Respondents' perceptions of the risk of heat shock at flowering and grain fill in cereals (n=111).

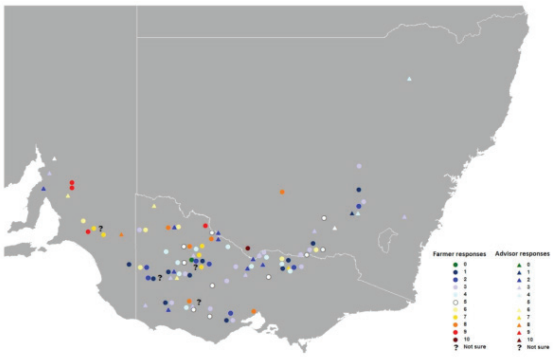

Figure 4. Geographic spread of responses to the number of years out of 10 that respondents think heat shock affects wheat at flowering and grain fill.

When asked about the ways that they mitigate against heat shock most farmers and advisors are sowing early and sowing a mix of crop types (Table 2). The use of early maturing varieties is surprisingly less common and once again varying sowing date is not popular. The selection of less susceptible crops is also not used regularly with 29% saying they never do it. The prevalence of early sowing against heat aligns with the practice of never sowing late for frost control. Early sowing in the frost window or even before the frost window often leads to a good outcome in the absence of a frost event due to grain fill occurring before heat stress occurs. This data highlights that growers are more intent on avoiding late season heat shock to crops by sowing early, more so than avoiding frost by sowing later.

Table 2. A comparison of popularity of a range of agronomic management options that are used or recommended to mitigate against heat shock in cereals.

	All the time	Most of the time	Some of the time	Never
Sowing early	16%	36%	35%	13%
Sowing earlier maturing varieties	10%	24%	53%	13%
Sowing a mix of crop types	19%	40%	26%	15%
Varying sowing dates	10%	22%	45%	23%
Grow less of the more susceptible crops	9%	18%	44%	29%

When this data is spatially displayed it shows that heat is clearly the greater concern, but the people who are concerned about frost are located to the west and north of the Great Dividing Range, with the exception of some of south-western Victoria respondents (Figure 5). Modelling work by DEDJTR has looked at the relative risk (low less than 33%, and high greater than 33% of years) of heat and frost occurring for a mid-season wheat sown on a defined autumn break (Barlow et al. 2013). There appears to be a good correlation between the perceived risks of respondents and the likelihood of frost and/or an extreme heat event.

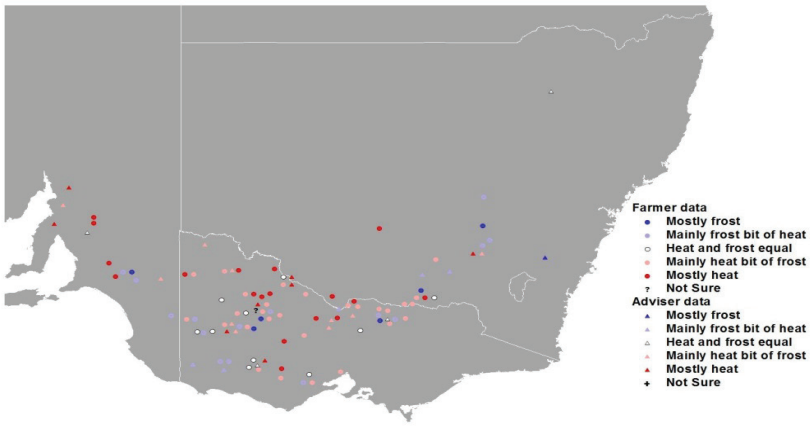

Figure 5. Geographical spread of respondents' perceptions of the relative effect of heat and/or frost on cereal yield.

Conclusion

This survey has provided a timely and useful snapshot of industry knowledge of climate variability shocks and their mitigation tools. Useful responses from 111 people were obtained with respondents spread throughout the grain growing areas of south-eastern Australia, with Victoria and the NSW Riverina predominating. The risk of frost was assessed by respondents as most commonly between 10% and 30% of the time whereas the risk of heat was less defined, varying between 10% and 80%. People's assessment of heat risk is more varied and warrants further work on both the effects and communication of heat risks.

A large number of respondents (59%) have never delayed sowing as a frost evasion strategy, suggesting that growers are mainly considering the yield penalties, associated with heat stress and drought, from later sowing over the potential frost advantages. The number of people treating areas differently to a larger extent (19%), indicates some farmers actively mitigating their frost risk in the known areas problems occur. Farmers are managing heat stress by sowing earlier with a mix of crop types, but the use of earlier maturing varieties is not widespread. The mitigation options the grains industry employs to avoid heat stress are not used with the same conviction as those to avoid frost.

Overall, the results from this survey have shown that growers and consultants are more concerned with heat stress than frost. However, these perceptions have likely been influenced by the millennium drought where heat stress and terminal drought at the end of the growing season were the dominant climatic challenges. There was evidence that the impact of heat shock on yield is not as clearly understood as the impact of frost.

Acknowledgements

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Association between wheat yield and temperature in south-eastern Australia

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Abstract
We analysed the yield of wheat in National Variety Trials to explore links with weather, with emphasis on temperature, using the method of Mercau et al. (*Agric Syst* 67, 83-103). Median yield for 182 wheat crops in the south-east was 3.1 t/ha. We separated high yielding crops (≥ 90th percentile, 4.9 t/ha) and low yielding crops (≤ 10th percentile, 1.4 t/ha). The crop cycle was split in 16, 100-^{o}Cd developmental windows centred at flowering of a mid maturity cultivar. Low yield was associated with low rainfall during establishment, grain set and late grain filling; high vapour pressure deficit during all the growing season; high minimum temperature during grain filling; high maximum temperature during most of the growing season; and low photothermal quotient corrected by vapour pressure deficit in the critical period of grain set before flowering. The relationships found are agronomically robust and provide a guide for experimental research but cannot be taken as proof of cause-and-effect because weather variables are confounded.

Association between wheat yield and weather
The aim of this work was to explore associations between wheat yield and weather, with emphasis on temperature. We analysed mean yield of 182 National Variety Trials (NVT) from the South East region between 2009 to 2013. Fig. 1 shows the frequency distribution of actual yield; the median was 3.1 t/ha, the 90th percentile 4.9 t/ha and the 10t^{h} percentile 1.4 t/ha.

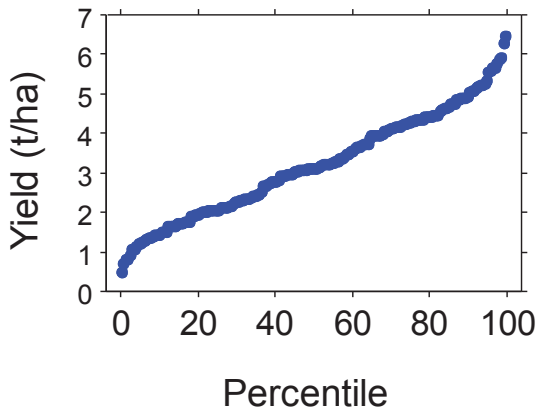

Figure 1. Frequency distribution of wheat yield in NVT in south-eastern Australia 2009-2013; n = 182.

We used APSIM to estimate flowering time of a mid-season cultivar for each NVT location and season, and the following variables were calculated for 100 ^{o}Cd (base = 0 ^{o}C) windows centred at flowering: rainfall, average vapour pressure deficit, average minimum and maximum temperature, number of days with temperature above 25°C and 30°C, incident photosynthetically active radiation (PAR), the photothermal quotient PTQ - the ratio between cumulative intercepted PAR and daily mean temperature (Fischer, *J Agric Sci* 105:447) and the PTQ corrected by vapour pressure deficit PTQvpd (Rodriguez & Sadras, *Austr J Agric Res* 58:287). The conditions associated with high (≥ 4.9 t/ha) and low yield (≤ 1.4 t/ha) were evaluated with the method of Mercau et al. (*Agr Syst* 67:83).

Low yield was associated with low rainfall during establishment, tillering and early stem elongation and late grain filling (Fig. 1A) and with high vapour pressure deficit during all the growing season (Fig. 1B). Of all the variables investigated, vapour pressure deficit was the one that showed the strongest and more consistent association with yield. The agronomically meaningful links between yield, rainfall and vapour pressure deficit reinforce our confidence in our analytical approach.

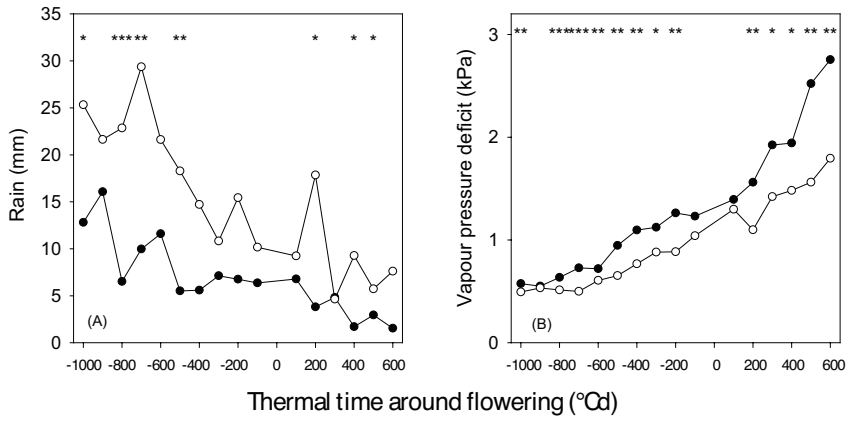

Figure 2. (A) Rainfall and (B) vapour pressure deficit associated with high (open symbols) and low (closed symbols) yielding wheat crops in south-eastern Australia. Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

Low yield was associated with high minimum temperature during grain filling (Fig. 3A). There was a strong and consistent association between low yield and high maximum temperature during most of the growing season (Fig. 3B). Low yield was related with more days with maximum temperature over 25 °C (Fig. 3C) and more days over 30 °C during grain filling. Maximum temperature exceeding these thresholds is unlikely before flowering, hence the lack of associations for the early part of the season. There was a weak association between low yield and high radiation late in the season that possibly reflects the link between high radiation and high temperature (Fig. 3E). Low yield was associated with low PTQvpd in the critical period of grain set before flowering, and there was a secondary association during grain filling. For this data set, yield and PTQ were unrelated.

Conclusion

We used an indirect method (sensu Bonada & Sadras *Austr J Grape Wine Res* 21:1) to explore associations between yield and weather. The relationships found are agronomically robust, but cannot be taken as proof of cause-and-effect. Weather variables are confounded because they are related in time over short (day) and long scales (season or longer) and they are also related in space, e.g. dry locations normally have higher temperature and higher radiation (Rodriguez & Sadras, *Austr J Agric Res* 58:287). Of particular interest, the strong signature of vapour pressure deficit deserves work to untangle the effect of temperature per se and the effect of temperature mediated by vapour pressure deficit. Direct manipulation of temperature in field experiments is necessary.

Acknowledgements

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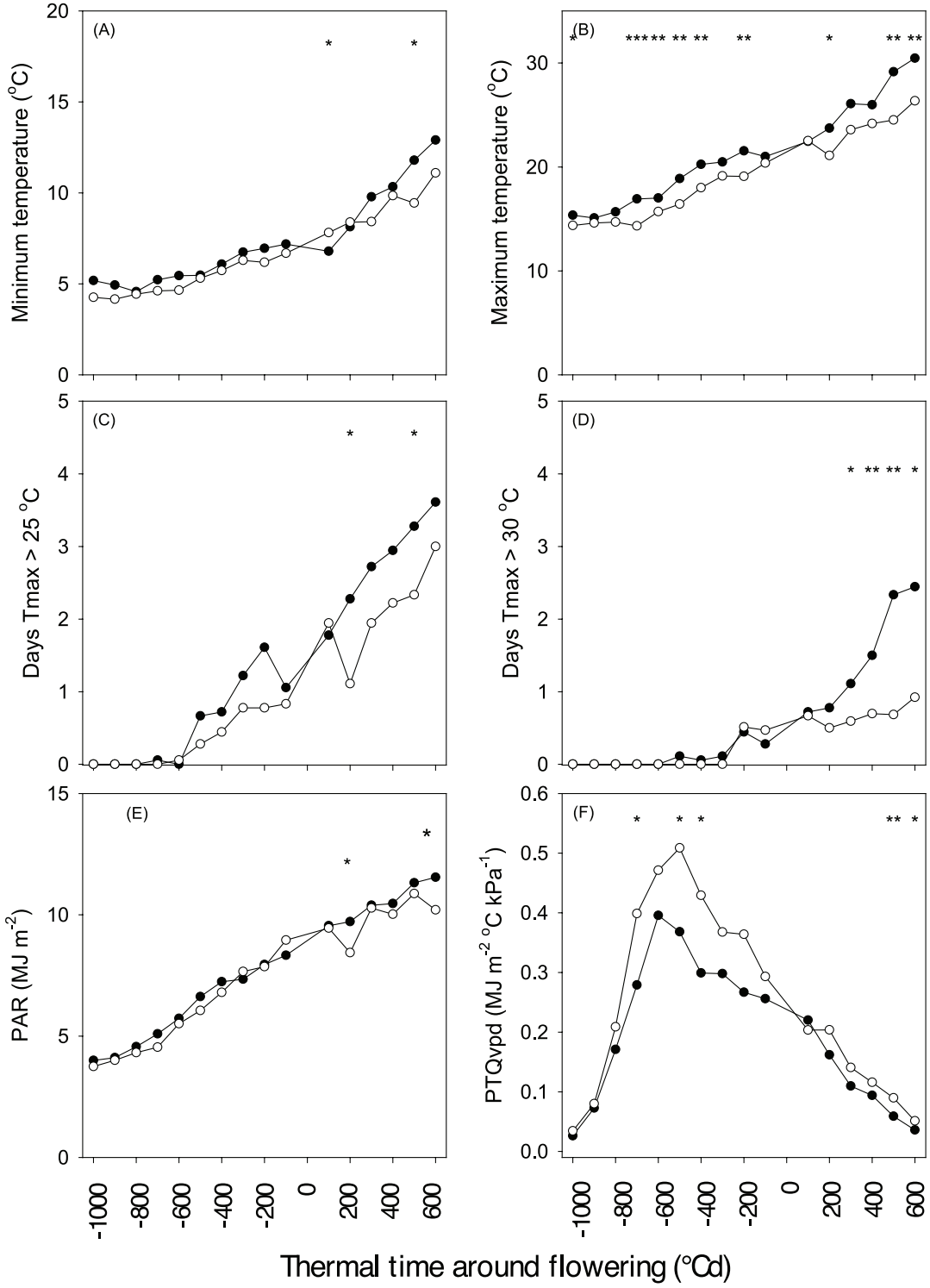

Figure 3. Photothermal conditions for high (open symbols) and low (closed symbols) wheat yielding crops in south-eastern Australia. Asterisks indicate significant differences at P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

Genotypic heat tolerance in lentil

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Abstract
Heat waves (temperatures > 35°C) during flowering and pod-filling of lentil can result in significant reductions in seed yield, quality and profitability. Preliminary research for improving adaptation of lentil to heat stress has found potential genetic variation in tolerance within lentil genotypes during the reproductive phase. A field study during the 2014-15 summer in southern Australia investigated the genotypic variation for heat tolerance of 50 lentil genotypes. Late sown crops were grown under unshaded (heat treatment) and shaded (control) conditions through the reproductive phase and irrigated to avoid moisture stress. Seed yield response to heat treatments ranged from -100% to -20% relative to controls (shade) with a significant interaction between heat treatment and genotype. Several genotypes were more tolerant to heat stress compared to the commercial varieties these being 72578 (India), 70549 (Argentina), 71457 (Jordan) and 73838 (Albania) with yields 65%, 72%, 75% and 80% of the controls respectively. These genotypes had improved heat tolerance compared with current commercial varieties and also had equivalent absolute yields. The impact of heat stress was primarily a reduction in seed number, which was reduced by 50% for commercial cultivars compared to 18% for landraces identified to have improved heat tolerance. Further controlled experimentation of these genotypes is required to validate their genetic potential. The identification of potentially tolerant genotypes to heat stress indicates there is an opportunity to utilize genetic differences to high temperatures during the reproductive phase of lentil, thereby improving their adaptation to heat waves.

Additional Key words
Climate change, genetic variation, pod filling, pulses.

Introduction

The rain-fed cropping regions of southern Australia have a Mediterranean-type climate, where crops frequently mature into terminal drought conditions. The occurrence of heat waves often coincide with the reproductive and grain filling phase of crops and can have significant impacts on their yield and quality. For southern Australia, the frequency of heat waves has been predicted to increase from a 1-in-10 to a 1-in-3 year occurrence (IPPC, 2012). Lentil crops are frequently included in cropping rotations and are particularly sensitive to abiotic stress. The potential impact of heat waves to lentil production poses a significant challenge to the grains industry. For example, a heat wave (35°C for 6 days) in 2009 across south-eastern Australia caused a 70% yield reduction in lentil crops, equating to $1000/ha loss (Brand, pers. comm).

The severity of the damage caused by heat stress depends on timing. Pulse crops including lentil are particularly sensitive to the effects of heat stress at the reproductive stages of development when plants are in full bloom. Even a few days of high temperature (30 -35°C) limits many processes including photosynthesis, metabolic pathways, electron flow and respiration rates (Redden et al, 2014), causing flower and pod abortion, resulting in yield losses by reducing seed set, seed weight and accelerating senescence (Siddique, 1999; Gaur et al., 2015). Adaptation of lentil to heat waves may be managed through avoidance (and involves selecting early maturing genotypes) or alternatively genetic solutions through identifying and breeding additional tolerance into commercial lines. Heat tolerant lentil genotypes exist and allow flexibility in sowing dates and enhance opportunities for improving yield stability and expanding areas of pulses to new cropping systems (Gaur et al, 2014). However, this genetic potential has not been fully explored in lentil for the purpose of adaptation to heat stress. The current research assesses the heat stress tolerance of a broad range of lentil genotypes and compares their response with current commercial varieties to determine if potential genetic solutions exist for increasing lentil tolerance to heat stress.

Material & Methods

Fifty lentil genotypes were tested for response to high temperature under field conditions. The study included nine commercial cultivars and 41 accessions. The accessions were selected from a range of countries and climatic zones, particularly regions where heat stress events are common in the natural growing conditions,

such as, Syria, Turkey and Pakistan (Fig 1).Genotypes (varieties and accessions) displayed a range of growth habits, flowering and maturity. These accessions were sourced from the Australian Grains Genebank, Horsham Victoria. The nine commercial breeding lines were a representation of the current cultivars commonly included in cropping rotations in southern Australia, with a range of adaptations to biotic and abiotic stresses, as a result of recent breeding. The breeding checks CIPAL0901, an early maturing red lentil breeding accession and the commercial variety PBA Giant, a large green mid/late maturing lentil were used as control lines in this experiment (checks grown every 12 rows).

Figure 1: World map showing the origins of the genotypes included in this late sow field trial.
***Algeria (70156), Bulgaria (70951), Cyprus (71698), Egypt (73364), Greece (73580), Iran (72860), Jordan (70478), Lebanon (70118, 71456), Libya (73693), Morocco (70457), Syria (70402, 70400, 70569, 71119, 70392), Turkey (70685, 72366, 73252, 70138)**

The trial was sown under field conditions at Horsham, Victoria on a grey Vertosol soil. Sowing was delayed until 17 October to force the flowering window of lentil into hotter growing conditions (36 days >33°). The trial was a randomised complete block design with two replicates and single 1 m rows (112 rows/rep) sown, 0.65 m apart on a pre-watered irrigation bay (150 mm).Control plants were grown under a shade facility (50% shade, white UV stabilised high density polyethylene fabric, installed 0.75 m above the ground) from anthesis through to maturity, and compared with the equivalent plants grown in full sun. Between sowing and the average anthesis date (3/12/2014) there was 22 mm of rainfall and 108 mm of supplementary irrigation and in the post anthesis phase up to harvest 64.5 mm of rainfall and 36 mm of irrigation. Temperature was recorded for the canopy, soil and air for both growing conditions (unshaded and shade). Crop phenology was also recorded. At harvest, the above-ground biomass was harvested and total biomass, seed yield and seed number determined.

Results and Discussion

Lentil exposed to full heat (unshaded) had average grain yields lower (66% reduction) than those grown under the shaded control, which demonstrates the effectiveness of the shade facility in reducing plant heat stress. A similar approach has been used by Krishnamurthy et al (2011) where genotypes were grown in contrasting conditions, using sowing dates (normal and late) and different climates. For the current experiment the shade facility reduced radiant heat (non-limiting to photosynthesis) by 38.5% with a decrease in canopy temperature of 2.5°C. There was increased pod and leaf drop for plants grown in full sun, which is a common coping mechanism for pulse crops suffering from heat stress (Erskine et al, 2011).

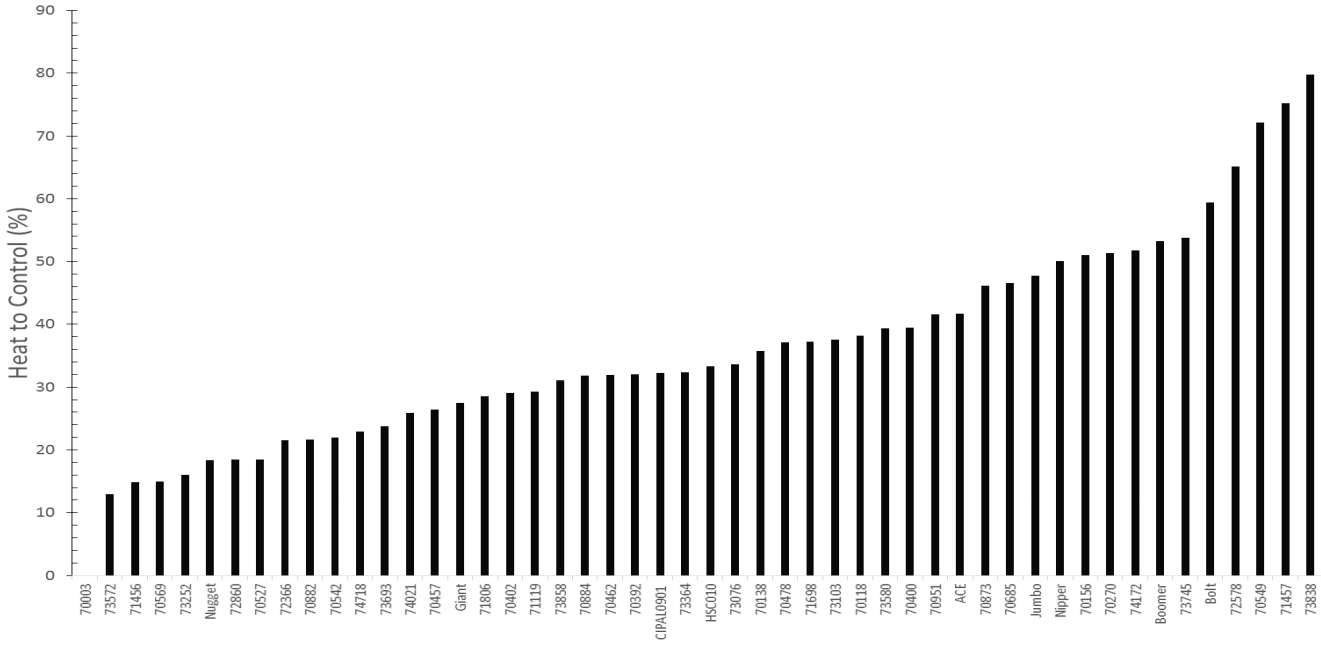

Fig 2: The response of heat stress (unshaded) crops on grain yield, relative to the control (shaded) crops for the genotypes (heat to control %).

The average yield of commercial cultivars was reduced by 41%, for heat stress plants (unshaded plots) compared with their respective controls (shaded). PBA Bolt and Boomer showed the greatest heat tolerance with yield reductions of 35 and 47%, respectively. Nugget and PBA Giant were the most sensitive to heat stress with yields reduced by 82 and 73%, respectively (Fig 2). Four genotypes, 72578 (35% reduction), 70549 (28% reduction), 71457 (25% reduction) and 73838 (20% reduction) showed improved tolerance to heat stress compared with the most tolerant commercial variety, PBA Bolt. For the four heat tolerant genotypes identified and PBA Bolt, the average seed number was reduced by 18% compared with 75% for the most sensitive genotypes (< PBA Giant). In contrast, the seed size reduction under heat stress (unshaded) for the two groups was equivalent (14%), which suggests that grain number is the major yield component being reduced by heat stress. This is consistent with Gaur et al (2015) who found that the ability to fill pods with seed is correlated with improvements in heat tolerance. The origin of the genotypes identified in this study to be more tolerant to heat stress were India, Argentina, Jordan and Albania, which have Mediterranean to Arid type climates, with a high probability of high temperature stress during the reproductive phase of crop growth (Fig 1). Genotypes from more temperate or tropical zones were more sensitive to the harsh conditions and in some instances failed to either reach maturity or produce yield.

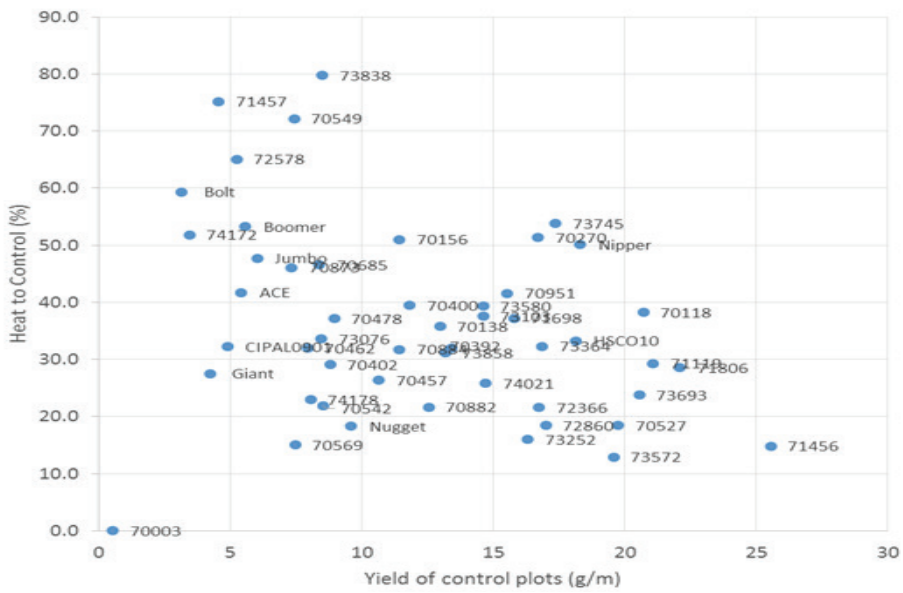

Figure 3: The relationship between the absolute yields for the control crops (shaded) and the heat to control % (increases with heat tolerance).

When comparing the absolute yield of lentil genotypes under control conditions (shaded) and the response to heat stress (heat to control %) we identified several genotypes that are both tolerant to heat stress and have an adequate absolute yield under control conditions (Fig 3). Some genotypes were high yielding, but generally had poor tolerance to heat stress. In contrast, the genotypes identified with high tolerance had a relatively low absolute yield. The majority of the commercial varieties had a relatively low absolute yield and poor tolerance to heat, the exception being Nipper, which had moderate tolerance to heat and absolute yield. The absolute yield of genotypes 72578, 70548, 71457 and 73838 was equivalent to the average commercial variety absolute yield, differing by an increase in tolerance (Fig 3). This indicates that there are lentil genotypes that have competitive agronomic yield and a greater heat stress tolerance.

The plants grown in the shade had a delayed rate of pod set and maturity, compared to the unshaded plants. The delay in maturity was likely to be due to the reduction in temperature and increased moisture conservation under the shade. There was no significant interaction in the relative delay in maturity and genotype under the two treatments (shaded/unshaded). While there was no significant correlation, the genotypes most tolerant to the heat treatment (70549, 71457 and 73838) were earlier to mature. In general, the commercial varieties had a faster rate of development compared to other genotypes, despite not necessarily having improved heat tolerance (Fig 2).

Conclusion

Genetic variability in the response of 50 lentil genotypes to imposed heat stress during the reproductive stage has been demonstrated. Four genotypes have been identified (72578, 70549, 71457 and 73838) to have improved tolerance to high temperature and absolute yield equivalent to current commercial cultivars. This provides the opportunity for breeding programs to improve the tolerance of lentil to heat stress, leading to better yield stability and profitability for growers. Further controlled studies are required to validate these early findings, refine screening methods and investigate mechanisms inferring tolerance.

Acknowledgements

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Harvest weed seed control: ryegrass seed retention levels in south-eastern Australia wheat crops

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Abstract
Herbicide resistant weeds are a major impediment to Australian grain production and solutions to this problem are required. One of the newer methods used to reduce their impact is the collection and/or destruction of weed seeds at harvest, harvest weed seed control (HWSC). A major premise of HWSC is that the targeted weed species retain a high proportion of their total seed production at crop maturity and that this seed is subsequently collected during harvest. The adoption of HWSC systems in Western Australia has been driven by high annual ryegrass seed retention levels recorded in wheat production systems. The lack of seed retention data is likely restricting adoption of these systems across the Southern region cropping systems. To determine annual ryegrass seed retention levels in southern region, sampling was undertaken in 2013 within seven days of crop maturity (first opportunity to harvest) in 46 wheat crops located across southern NSW and Victoria. At each location wheat and annual ryegrass dry matter production, grain yield and weed seed number was determined for each of five cutting heights (0,10, 20, 30 and 40 cm) as well as from the soil surface. Overall, 80% (48-100%) of ryegrass seed was found at greater than 10 cm above the soil surface and 69% (23–100%) above 20 cm indicating that HWSC can be a valuable tool for NSW and Victorian farmers in reducing weed seed burdens. However, with the large variability shown between locations in this study the efficacy of HWSC will vary considerably.

Key words
Herbicide resistance management

Introduction

A significant proportion of crops grown across the cereal growing regions of southern New South Wales and Victoria contain herbicide resistant annual ryegrass populations with many of these resistant to multiple herbicide modes of action (Boutsalis, et al. 2012; Broster, et al. 2011; Broster, et al. 2013). With herbicides the dominant weed control method the risk of herbicide resistance evolution is high posing a significant threat to the few remaining effective herbicides. As a result both farmers and researchers are investigating alternate methods of weed control that reduce the reliance on herbicides.

Many of the major annual weeds of Australian cropping retain their seed at maturity (Walsh and Powles 2014) and this has been identified as a key weakness of these species that can be utilised by farmers to prevent seed bank inputs. While the harvest process is an important factor in the spread of weed seeds across the paddock (Blanco-Moreno, et al. 2004) it can also be an opportunity to restrict their contribution to the seed bank. A number of HWSC systems have been developed to target weed seed during the harvest process thereby reducing inputs into the seed bank. These include narrow windrow burning, chaff carts and the Harrington Seed Destructor (Walsh, et al. 2013). A major principle of these systems is that the proportion of weed seeds that are collected at the front of the harvester indicates the amount of weed seed they prevent from entering the seed bank.

HWSC systems have been extensively adopted by farmers in Western Australia as a result of the high levels of herbicide resistance in both annual ryegrass and wild radish found across the WA cropping regions (Owen, et al. 2014; Walsh, et al. 2007). Adoption has been slower in south-eastern Australia for a number of reasons, one of which has been the lack of localised data. This study aimed to address one of these issues, the height at which ryegrass seed was located within a wheat crop; this determines the harvest height necessary to collect the majority of weed seeds and thereby indicating the maximum potential benefit from HWSC systems.

Materials and Methods

Between October and December 2013, 46 wheat crops grown in a range of environments (low rainfall - irrigated) were sampled across southern New South Wales and Victoria (Figure 1). At each site wheat and annual ryegrass plants were collected from four, 1.0 m^2 quadrats at five cutting heights, 0, 10, 20, 30 and 40 cm above the soil surface at the time of wheat crop maturity (first opportunity to harvest). Additionally, the soil surface within quadrat area was swept with a brush to collect any seed, seed heads and plant material that had fallen from plants. The number of wheat and ryegrass plants were also counted in each quadrat.

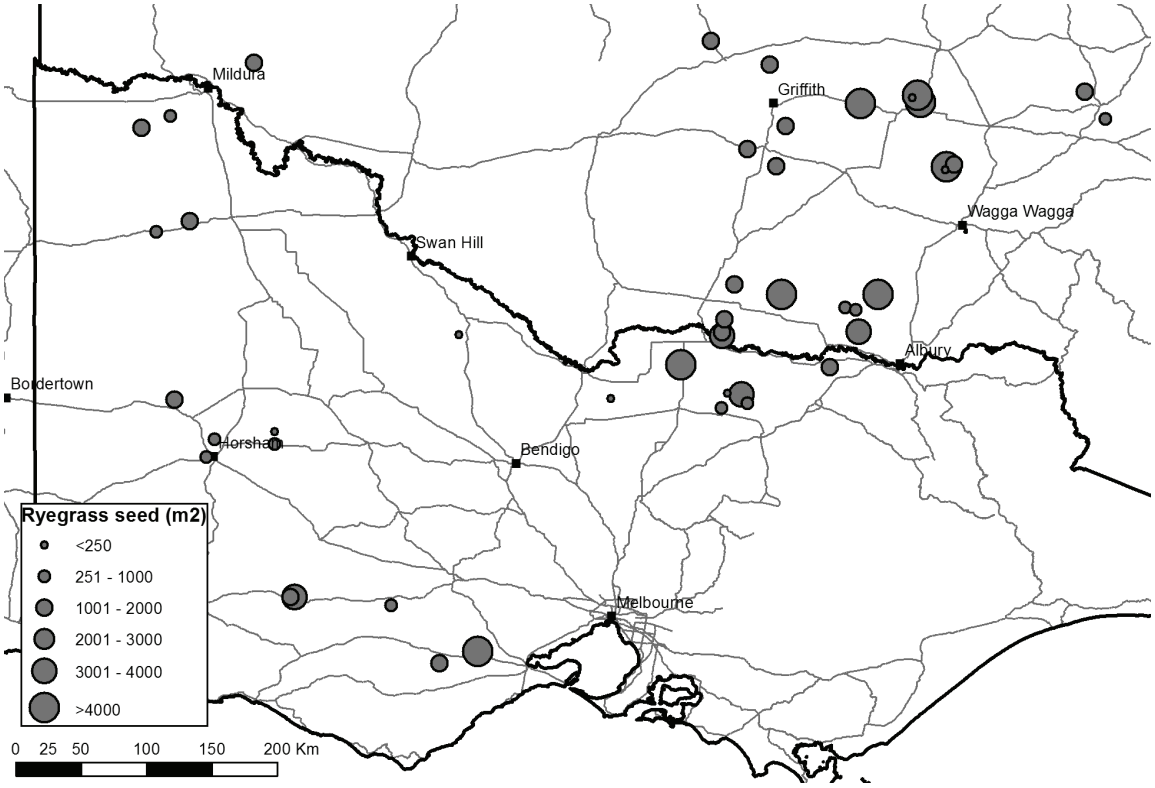

Figure1: Location of paddocks sampled across Victoria and southern NSW for the determination of annual ryegrass seed retention height at wheat crop maturity showing ryegrass seed densities at each site.

Before processing, the collected plant samples were oven dried at 70°C for 48 hours and then weighed. The samples were then sorted to separate wheat and ryegrass plant material. Any wheat heads present at each sample height were threshed and weighed to determine crop yield and proportion of yield at each sampling height. The ryegrass samples were weighed to determine dry matter production, threshed and then the seed produced was counted to determine seed production at each sampling height.

The percentage of ryegrass seed collected above each of the harvest heights was calculated for each site. For each variable measured the lowest and highest fifteen sites were then determined and the mean percentage of ryegrass collected above each harvest height was also determined for these sub-samples of sites. Standard errors were then calculated for the overall mean, lowest 15sites and highest 15 sites to allow the observation of differences between these categories.

Results

The mean wheat density was 65.6 plants/m^2 (range 13.0 – 122.25) producing 8.6 t/ha of dry matter (1.6 – 16.4) and 3.68 t/ha of grain (0.5 – 8.6) with a mean harvest index of 41.3%. The average number of ryegrass plants recorded was 8.5/m^2 (1.0 – 50.8) producing 168 kg/ha of dry matter (6 – 1145) and 1889 seeds/m^2 (87 – 7192) or approximately 18.9 million seeds per hectare.

Overall 93% of the ryegrass seed had been retained by the plants at the time of sampling, 80% (range 48-100) was above 10 cm and 69% (range 23-100) above 20 cm. As estimated from the plotting of height against seed production, at a 15cm harvest height there was no difference in the proportion of ryegrass seed

collected between the mean (75%), lowest (76%) and highest (75%) yielding sites (Figure 2a). However, a higher percentage of ryegrass seed was found above both 30 and 40 cm harvest heights in the higher yielding crops compared with both the overall mean and the lowest yielding crops (Figure 2a). A similar finding was also recorded for the sites with the lowest and highest wheat dry matter production.

Table 1: Wheat and ryegrass production across 46 sites in south eastern Australia

	Mean	Minimum	Median	Maximum
Wheat				
Plants (no./m^2)	65.6	13.0	65.6	122.3
Dry matter (t/ha)	8.6	1.6	8.2	16.4
Yield (t/ha)	3.7	0.5	3.2	8.6
Harvest index (%)	41.3	16.7	41.6	57.5
Ryegrass				
Plants (no./m^2)	8.5	1.0	4.3	50.8
Dry matter (kg/ha)	168	6	90	1145
Seed production (seed/m^2)	1889	87	1254	7192

A greater percentage of ryegrass seed at all harvest heights was recorded in the paddocks with lower ryegrass densities when compared with paddocks with higher annual ryegrass plant density. In the paddocks with the highest annual ryegrass densities less seed (66.4%) was found above a 15 cm harvest height compared with the paddocks with lowest annual ryegrass plant densities (80.1%) (Figure 2b). Conversely, high annual ryegrass dry matter production or annual ryegrass seed production resulted in higher percentages of seed found at all heights compared with the overall mean, there were minimal differences between the low wheat production paddocks and the mean.

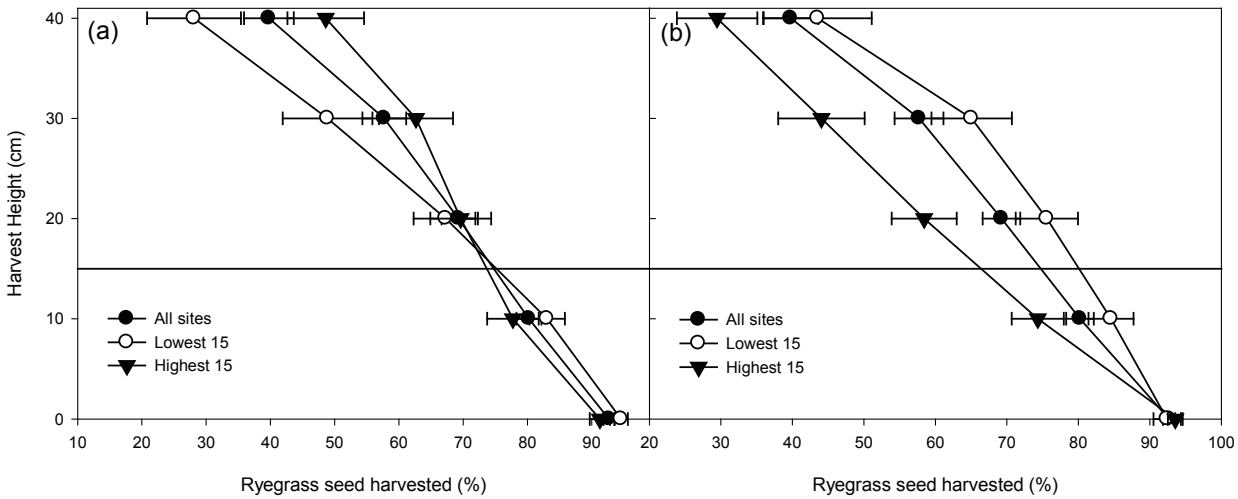

Figure 2: Percentage of annual ryegrass seed located above five harvest heights (0, 10, 20, 30 and 40 cm) for wheat yield (a) and ryegrass plant number (b). Lines represent the mean (± SE) for all sites, the 15 lowest sites and the 15 highest sites for each parameter. The horizontal line indicates a 15 cm harvest height, the standard for HWSC in Western Australia.

Lowering the harvesting height by 10 cm resulted in a greater than 10% increase in the amount of ryegrass seed collected. The associated increase in wheat dry matter collected was less than 10% and at least 90% of this was straw or leaf material and not chaff or grain (Table 2).

Discussion

The high proportions of annual ryegrass seed retention on upright tillers at wheat crop maturity determined that a harvest height of 15cm allowed the collection of 75% of total annual ryegrass seed production. However, there was considerable variation in annual ryegrass seed retention height associated with wheat biomass production. The optimum conditions for annual ryegrass seed collection occurs in higher yielding crops. Higher yielding crops have greater levels of dry matter production forcing annual ryegrass plants to

grower taller to compete for light and consequently producing seed higher in the crop canopy. That lower annual ryegrass numbers were also related to a higher potential for ryegrass seed collection agrees with previous research that found lower pre-harvest ryegrass seed numbers also had larger proportional reductions in plant density the next season (Walsh, et al. 2014).

Table 2: Average wheat dry matter production, wheat yield and annual ryegrass seed collected at five harvest heights for 46 sampling sites across Victorian and NSW. Numbers in brackets indicate % of total.

Harvest height (cm)	Wheat DM* t/ha (%)	Wheat yield* t/ha (%)	Ryegrass seed* no. (%)
0	0.80 (9.4)	0.02 (0.4)	223 (12.5)
10	0.66 (7.6)	0.01 (0.3)	207 (11.6)
20	0.62 (7.2)	0.01 (0.4)	207 (11.6)
30	0.77 (7.8)	0.05 (1.4)	302 (16.9)
40	5.83 (68.0)	3.58 (97.5)	847 (47.4)

* Dry matter and seeds found on the soil surface excluded from calculations.

A major concern raised by farmers when discussing HWSC systems is the need to harvest lower than normal and dramatically slowing the harvest operation. As observed in this study the majority of wheat grain (98%) was located above 40 cm however, the majority of annual ryegrass seed production (88%) occurred above 10 cm. At a 40 cm harvest height approximately 5.8 t/ha of biomass, 60% of which is grain, is processed. Here we found that the majority of additional crop material entering the harvester by harvesting at 10 cm instead of 40 cm is straw and leaf material only (Table 2) which requires minimal processing when compared with wheat heads.

This research has shown that HWSC systems have potential to be a useful management tool for NSW and Victorian farmers in reducing both weed seed burdens and their reliance on herbicides. However the large variability shown in this experiment its effectiveness will vary depending upon location, crop yield and ryegrass density.

Acknowledgements
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Improving herbicide tolerance in pulses to support the diversification of Australian crop rotations

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Abstract
Pulse crops are an essential component of sustainable intensive cropping systems in Australia, offering rotational benefits such as pest and disease breaks, improved soil health and reduced reliance on synthetic nitrogen sources. Broadleaf weeds are a major limitation to pulse production as there are limited safe or suitable herbicide control options available. Metribuzin is a broad-spectrum herbicide, which offers control of a number of key broadleaf and grass weeds in a range of pulse crops. However, metribuzin activity is variable under different soil and seasonal conditions and can cause significant yield loss at registered rates and timings in pulse crops, resulting in the usage of lower rates and reduced weed control. Studies in other crops have shown variation in tolerance exists to metribuzin, and genotypic variation has been identified in pulse herbicide tolerance trials in Australia. Identification of lines with improved levels of tolerance would improve crop safety and weed control. However, metribuzin can be difficult to screen under field and glasshouse conditions due to its variable activity. This paper reports on the development of new rapid, repeatable, high-throughput and inexpensive screening methods for identifying metribuzin tolerance in lentil, field pea and faba bean, as well as their comparison to field results. A high level of agreement between the new methods and field results was observed, and over 200 diverse accessions of each crop were screened for tolerance. These methods are now being used to incorporate improved levels of metribuzin tolerance into Pulse Breeding Australia (PBA) breeding programs.

Key words
Legumes, Metribuzin, germplasm, resistance, method, validation

Introduction
Pulse crops are an important component of Australian farming systems and provide a number of rotational benefits, such as disease and pest breaks, reduced energy inputs through nitrogen fixation and improved soil fertility (Rubiales and Mikic 2015). With an increasing need for greater temporal diversity in cropping sequences, the benefits of pulse crops will continue to play an important role in the future of sustainable systems (Drinkwater, Wagoner et al. 1998). However, one of the major limitations to Australian pulse production is weed competition, due to the lack of herbicide control options (Siddique, Johansen et al. 2012). Herbicide control is the main method of weed control in modern-day no-till farming systems, however pulses have limited suitable or safe herbicide control options available and many of the registered options in pulses, such as metribuzin, have low safety margins between phytotoxicity to the weed and to the crop (Brand 2012). Furthermore, there is an increasing need to maximise the use of available products, with the decreasing number of new herbicides being introduced, the deregulation of older herbicides, and the reduced efficacy of some current products due to the increasing number of herbicide resistant weed species.

Metribuzin is a broad-spectrum Group C herbicide which works by blocking the electron transport system in photosynthesis, (Trebst and Wietoska 1975). Metribuzin has both foliar and root uptake, however its activity is highly variable depending on soil type and environmental conditions such as light intensity, temperature, soil moisture and humidity (Phatak and Stephenson 1973, Peter and Weber 1985). Metribuzin is commonly used in pulse crops as a post-sowing-pre-emergent application, or in some cases as a post-emergent; however can often result in crop damage (Brand 2012) or the use of lower than recommended rates.

The development of pulse germplasm with improved tolerance to metribuzin will help to reduce yield loss from crop damage as well as support alternative application rates and timings, improving weed control and grower confidence in pulse production systems (Yadav, McNeil et al. 2007). Variation in tolerance to metribuzin has been observed in pulse varieties through Pulse Breeding Australia (PBA) and National Variety Trials (NVT) herbicide tolerance trials (Brand 2012); however field screening can be unpredictable from season to season, and is slow, expensive, and low throughput. Controlled environments, such as

glasshouse and growth rooms, have been used in the past for screening for metribuzin tolerance, however methods can be limited by access to spray facilities and variations in soil media.

This paper reports on the development of new rapid, repeatable, high-throughput and inexpensive screening methods for identifying metribuzin tolerance in pea, lentil and faba bean, as well as the direct comparison of the results of these methods with field trials. In addition, over 200 diverse accessions of each crop were screened for variation in tolerance using the methods developed with the aim of identifying lines with improved tolerance over current Australian varieties.

Methods

Faba bean, lentil and field pea lines previously identified to vary in metribuzin tolerance were compared in hydroponic sand experiments and field trials. Hydroponic sand methods were conducted in controlled environment rooms at the Waite Research Precinct, SA during 2011 and 2012 (Table 1). Experimental design was a RCB with four replicates. Pots 4.5cm in diameter and 9cm in depth for lentils, and 8 x 10 x 8 cm for faba bean and field peas, were filled using Waikerie sand with a 1cm base of washed blue metal stone. Pots were suspended in fabricated racks which allowed the complete drainage of each pot without inter-pot contamination. Faba bean was sown 2 seeds per pot, while field pea and lentil were sown 4 seeds per pot, and all pots were watered with ¼ strength Hoagland nutrient solution every 2-3 days. Pots were thinned to one faba bean plant and two field pea and lentil plants at a uniform growth-stage of 2-3 nodes prior to treatment. To ensure uniform uptake, pots were pre-watered to field capacity 2 hours prior to treatment. Preliminary trials (data not shown) were conducted to determine herbicide rates for each crop (Table 1), and all treatments were applied at 12 days after sowing (DAS) directly to the surface of each pot, flooding the soil surface in a "drenching" method and carefully avoiding any leaf contact. Pots were flushed using ¼ strength Hoagland nutrient solution at twice the quantity of treatment 24 hours after treatment. Plants were assessed 2 weeks after treatment for plant damage as percentage of necrosis.

Post-emergent metribuzin rate response field trials were conducted at Turretfield (2011) and Kybunga (2010 and 2012), in the Mid North of South Australia (calcareous clay loams). In South Australia, 2010 was a dryer than average season with only 49mm of rainfall recorded in June and July, compared to 97-110mm in 2011/2012. A RCB design with four replicates was used for each trial with a plot size of 1.5m by 5m. The metribuzin treatment rates were based on field label rates, with 180g/ha the lowest recommended rate for sandy soils, and applied using a hand held boom at the 5 node growth stage (Table 2). Best management practice was used throughout the seasons to control insects, pests and diseases and no other in-crop herbicides were applied. Hand weeding occurred when required to remove weed competition. Visual plant damage (percentage of necrosis) and grain yield were measured. All data from hydroponic sand experiments and field experiments was analysed using ANOVA in Genstat.

Table 1: Hydroponic sand experiment details, including lines and metribuzin treatment rates

	Location	Lines	Rate (ppm)
Faba bean	Temperature controlled glasshouse at 20°C	AF3109, Nura, Farah, 1952/1	50ml solution of: 0, 20, 40 and 100
Field pea	Growthroom 20°C/10°C day/night,16-h photoperiod	PBA Oura, Yarrum, Kaspa, Sturt	50ml solution of: 0, 4, 8, 12, 16, 24 and 48
Lentils	Growthroom 20°C/10°C day/night,16-h photoperiod	99-088L, 96-047L	30ml solution of: 0, 0.3, 0.6, 0.8, 1.0, 1.2 and 2.4

Table 2: Field experiment details, including lines and metribuzin treatment rates

	Site / Year	Lines	Rates (g/ha)
Faba bean	Kybunga 2012,	AF3109, Nura, Farah, 1952/1	0, 180, 360, 720
Field pea	Turretfield 2011,	PBA Oura, Yarrum, Kaspa, Sturt	0 , 180, 360, 720
Lentils	Kybunga 2010,	99-088L, 96-047L	0, 180, 380

In addition, approximately 200 diverse accessions of lentil, faba bean and field pea were screened for metribuzin tolerance using the hydroponic sand methods above. Two to four reps of each accession were screened in RCBD with check lines spatially replicated 8-20 times throughout, and results were analysed using ANOVA in Genstat.

Results & Discussion

Hydroponic screening method results and field results showed the same significant trends when comparing both plant damage scores and yield results across methods (Figure 1). In faba bean, AF3109 performed significantly better than 1952/1, with roughly 60% less plant damage at rates of 40 ppm in hydroponic studies as well as 60% higher yield at rates of 360g/ha in field studies. Commercial bean line Farah also suffered significantly more plant damage and yield loss when compared to AF3109, while Nura showed statistically the same level of tolerance across both methods. In the field peas, PBA Oura consistently had an improved level of tolerance to metribuzin compared to Sturt across both methods; with 50% less plant damage at rates of 8ppm in hydroponic sand studies and over 60% higher yield at rates of 360g/ha in field studies. In addition, field pea line Yarrum suffered significantly less damage and yield loss when compared to Kaspa at all rates. The lentils also showed consistency between hydroponic screening methods and field results, with 99-088L having significantly less plant damage and yield loss compared to 96-047L at rates of 0.6ppm in hydroponic studies and 180g/ha in field studies. It is noted in Figure 1 substantial damage to field pea and lentil occurred in the hydroponic methods at the lower end of the range of rates applied, and in future, the range of rates could be restricted.

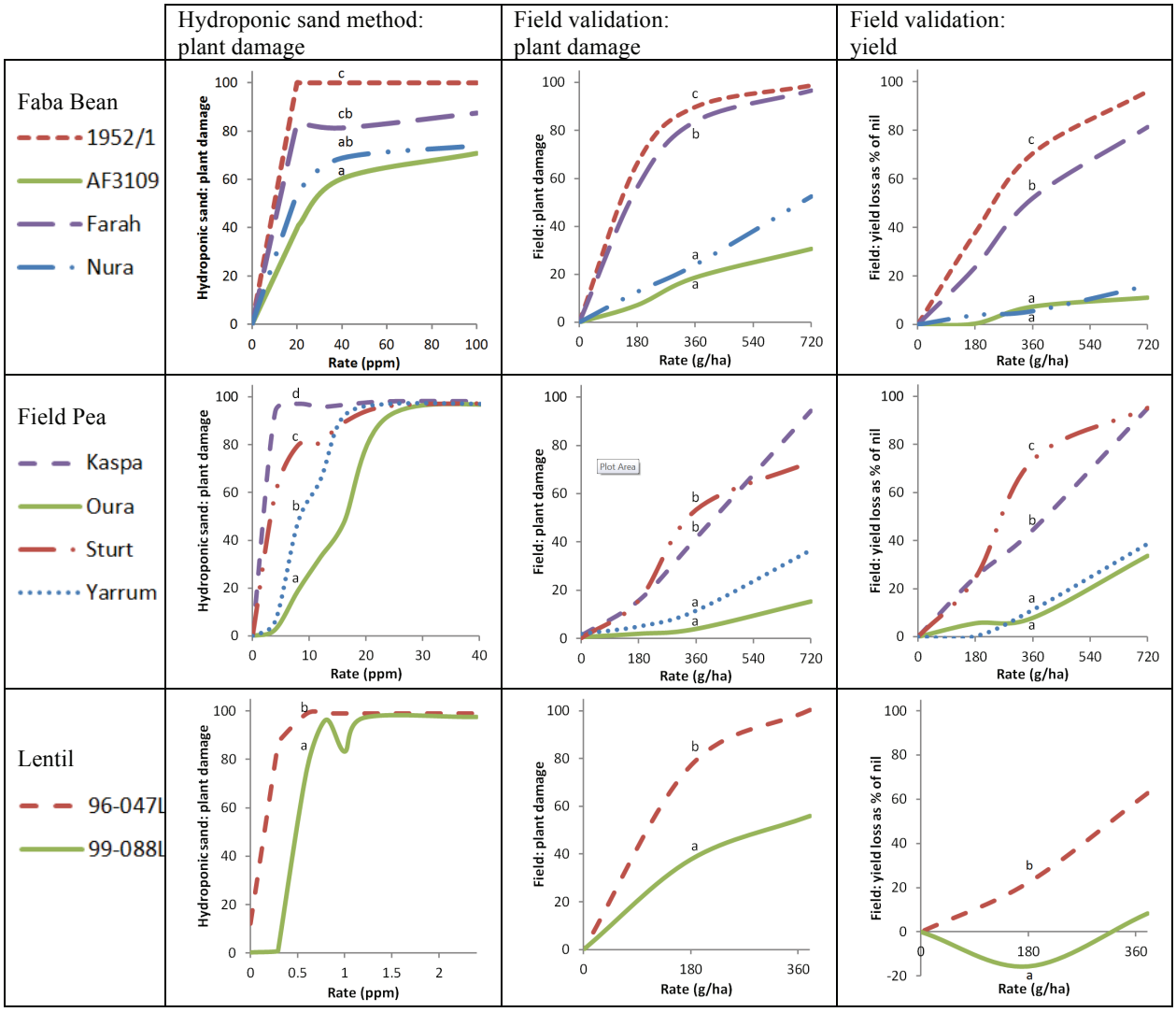

Figure 1: Results of hydroponic sand (plant damage) and field (plant damage and yield) trials in faba bean, field pea and lentil. Letters indicate significance at α=0.05 the major points of difference.

While the method of metribuzin application differed between hydroponic sand methods, which utilize root application, and field methods, which utilize foliar application, the results for all three crops were consistent across both methods for both plant damage and yield measurements. Previous work in this area has shown metribuzin to be similarly toxic regardless of whether absorption was via roots, shoots or seed zone uptake, and the method of application appears to be less crucial than the consistency of application (Fortino and Splittstoesser 1974). The hydroponic sand method allows a consistent application of metribuzin by eliminating inconsistencies in plant response caused by variations in soil and climatic conditions (De Weese, Wax et al. 1989). For example, the use of a sand based medium eliminates variability in herbicide

binding to organic matter and clay content, allowing the metribuzin to be more available for plant uptake, and lower rates are required to develop comparable levels of plant damage to field studies. Hydroponic methods have been successfully used to screen for metribuzin tolerance in other crops (De Weese, Wax et al. 1989), however as pulse crops are difficult to grow in controlled environment conditions (Summerfield and Muehlbauer 1982) and are sensitive to waterlogging, methods were developed to ensure optimum plant growth as well as a high level of metribuzin efficacy. Further, as metribuzin is highly soluble, flushing the system 24 hours after treatment allowed a consistent dose of the herbicide and reduced variation from herbicide persistence. The results showed that plant damage scores taken at 14 days after treatment (DAT) in hydroponic sand methods were sufficient at identifying agronomically useful levels of improved metribuzin tolerance in all three crops. The hydroponic sand method takes only 28 days, and can screen thousands of lines for metribuzin tolerance reliably, efficiently and inexpensively all year round.

Screening of 200 diverse accessions of each crop showed that genotypic variation existed for metribuzin tolerance in all 3 crops. About 95% of faba bean lines performed similarly to or significantly worse than commercial line Nura, however of the 5% with improved tolerance, 2 lines showed a significant level of improved tolerance compared to AF3109. Similarly, the screening of 200 diverse accessions of lentil also identified 5% of lines with an improved level of metribuzin tolerance compared to the commercial line PBA Flash. In contrast, none of the 200 diverse accessions of field pea screened showed a significant level of improved tolerance to metribuzin compared with the commercial line PBA Oura, though 3% of lines were identified as having a similar level of improved tolerance over the widely grown variety Kaspa.

Conclusion

These results confirm that variation in tolerance to metribuzin exists within faba bean, field pea and lentil germplasm, and the developed hydroponic sand methods can successfully identify lines with agronomically useful levels of tolerance. These methods could be applied in breeding programs to routinely ensure appropriate levels of tolerance are maintained within the programs. Furthermore, these methods could be applied to other crops as well as other herbicides, particularly those with similar chemical characteristics such as simazine and diuron, which also have low safety margins in pulses. The development of improved herbicide tolerance is critical to improving weed control in pulse crops, and expanding pulse production into new areas to support the diversification of Australian crop rotations.

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Dual direction allelopathy: the case of canola, wheat and annual ryegrass

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Abstract
The exploitation of allelopathy for enhanced weed suppression is in its infancy despite major advancements in our knowledge of weed suppressive cultivars. Crop species, including wheat and canola have been identified as potentially being weed suppressive against annual ryegrass. However, the contribution of crop allelopathy to interference is complex to elucidate within a field context. Traditionally, experiments involving allelopathy only investigate one species as the donor and the other as the target, irrespective of the putative duality of allelopathic responses between some species. In this paper we investigate dual direction allelopathic responses between canola and annual ryegrass at the seedling stage utilising laboratory growth assays, specifically the equal compartment agar method (ECAM). By manipulating experimental conditions, such as sowing density, time of sowing and plant proximity, we compare the efficiency of each species to exert an allelopathic effect on the other. Both species exert an inhibitive effect on the other dependant on the starting experimental conditions which they are subjected. We found that increasing the time that each species grows in the agar before introduction of the other species significantly inhibits the growth of the later sown species, up to 83.6% inhibition of canola root length by annual ryegrass. Density also played an important role in determining the level of root inhibition found for both species. Canola and wheat varietal differences were observed in respect to the level of annual ryegrass inhibition found. This paper discusses the implications of these results in the larger context of varietal selection for weed suppression.

Key words
Interference, plant competition, crop weeds, roots

Introduction
"*Interactions between neighbouring plants are so complex, tight and apparently impossible to disentangle that it may be wise to cease to look for simple effects*" (Harper, 1977). Australian farming systems, and increasingly global agriculture, have moved to conservation mode through reduction in tillage. For this to be successful, there has necessarily been a high dependence on herbicides for weed management. Herbicides have been highly efficacious in their abilities to control weeds but the continued evolution of weed resistance to many herbicides has threatened to undermine the conservation agriculture revolution. The need is apparent for there to be new options developed for weed control including a more intensive consideration of the plant's own capabilities to manage their own environments. The study of plant interference is gaining momentum although the current systems of plant breeding largely ignore the abilities of a variety to exercise control over its weed challengers.

The difficulty in studying interactions between plants is due to the complex nature of plant interference, defined as the combined effect of competition for resources, and allelopathy. Allelopathy is distinct from other forms of interference as it relies on the production of chemicals that may inhibit or enhance the growth of plants in close proximity. The ability of an individual plant to induce a negative effect on a neighbouring plant through chemically mediated changes in the immediate environment should be of great interest for breeding weed suppressive crop cultivars. The challenge however experimentally is that demonstrating the effect of allelopathy in the absence of other interference components may lead to erroneous conclusions when relating results back to a field context. Moreover, the difficulty in conceptualising chemical interactions between two or more species impedes our understanding further. Nevertheless, great advancements have been made in disentangling some of these interacting effects and applying allelopathy to weed control.

Wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.) are Australia's first and third largest broad-acre crops respectively. In particular, the future prospects for the Australian canola industry are excellent. Good

commodity prices, market demand, and canola's usefulness in the farming system as a break crop make canola an attractive alternative crop for grain growers. However, losses due to weed pressure is a major yield limiting factor of canola (Lemerle *et al*., 2012). Weed such as annual ryegrass (*Lolium rigidum Gaud*.) limit attainable yields of many broad-acre crops. The rapid evolution of herbicide resistance in annual ryegrass limits control options and call for integrated control methods such as allelopathic crop varieties.

The development of crops with the capability to exert allelopathic effects on crop weeds through root exudates is an attractive prospect (Olofsdotter *et al*. 2002). Research has shown this potential in wheat (Wu *et al*. 2000), barley (Bertholdsson 2004, 2005; Lovett, 1994), rice (Dilday *et al*. 1994; Seal et al. 2004; Gealy *et al*., 2005), and canola (Asaduzzaman *et al*., 2014). In these studies, the genetic variation of crop cultivars tested yielded a range of allelopathic responses and the identification of highly expressing genotypes.

Allelopathy is a multi-directional process

It is now possible to use a relatively simple method to evaluate the impact of one species on another through chemical exudates. The Equal Compartment Agar Method (ECAM) developed by Wu et al. (2000b) is now widely used and there is strong correlation evidence that the laboratory outcomes link closely with performance in the field (Asaduzzaman et al., 2014; Seal *et al*., 2004). In most cases for production agriculture this effect has been a study of crop on weed. What is usually ignored is the reverse reaction where the weed also exudes chemicals that potentially compromise the impact from the crop (Moore *et al*., 2010). This is shown in Figure 1 for wheat and Figure 2 for canola.

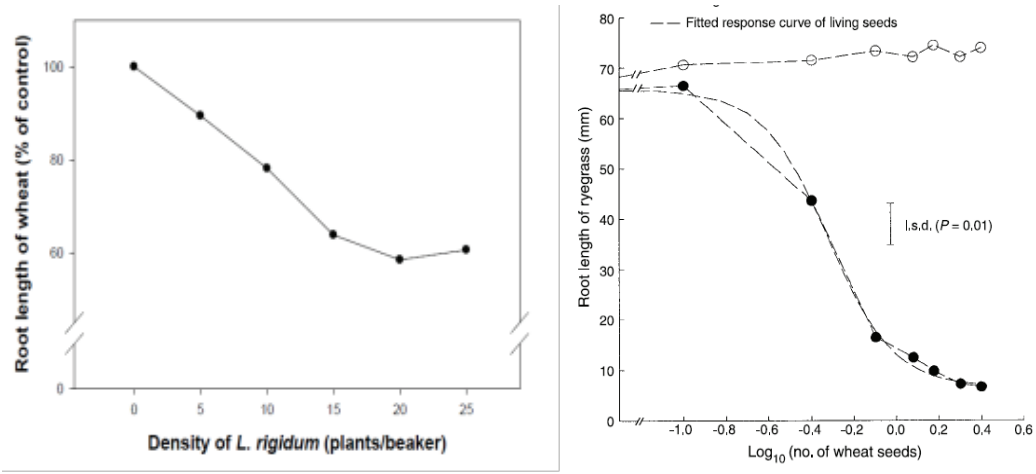

Figure 1. Effect of annual ryegrass density on root length of wheat (LHS – Moore *et al*., 2010) and effect of wheat density on annual ryegrass root length (RHS Wu *et al*., 2000)

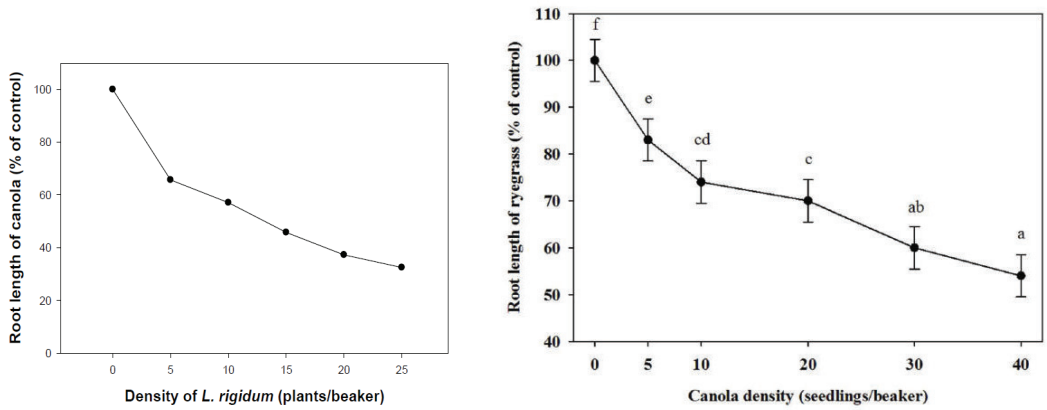

Figure 2. Effect of annual ryegrass density on root length of canola (LHS – Moore *et al*., 2010) and effect of canola density on annual ryegrass root length (RHS – Asadazzuman *et al*., 2014)

Consideration of the interaction in only one direction therefore may lead to outcomes in the field that do not support the notion that the crop may be able to provide itself a degree of weed control.

There is variation in potency across varietal germplasm

In order to make progress it is important to explore the range of potency present in the crop germplasm. This has been done in the Australian context for both wheat (Wu *et a*l., 2000b) and canola (Asaduzzaman *et al*., 2014). These investigations show that there is large degree of variation between varieties in their impacts on annual ryegrass. In the case of wheat Wu *et al*. (2000a) demonstrated that there was a strong link to genetic lines. It makes sense that the most potent of these varieties are further considered and evaluated under field conditions as demonstrated by Asaduzzaman *et al*., (2014b).

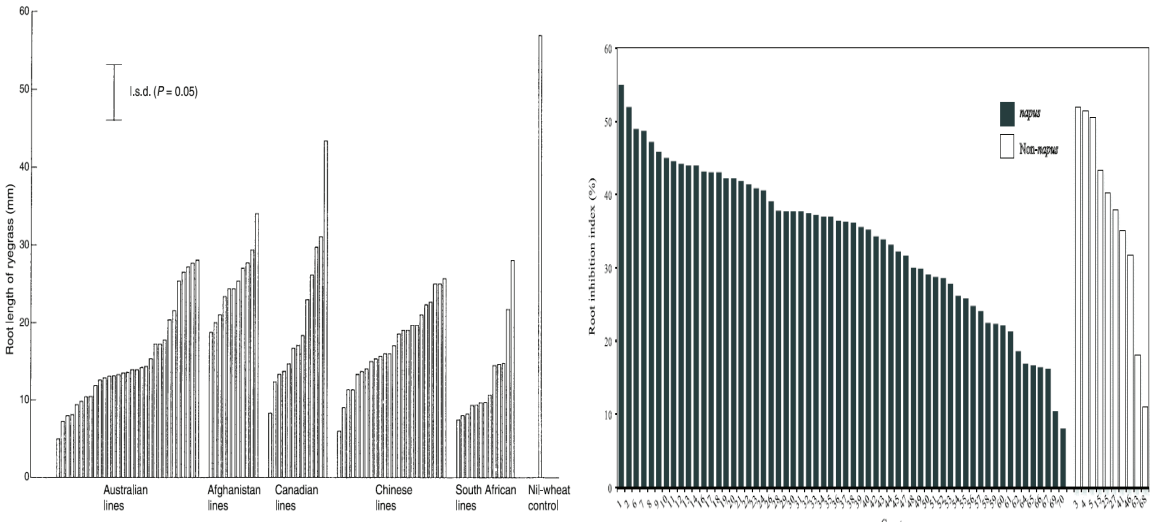

Figure 3. The effect of variety of wheat (LHS – Wu *et al*., 2000) and canola (RHS – Asaduzzaman *et al*., 2014) on root growth of annual ryegrass.

What then is missing from these studies is the evaluation of the strong allelopathic varieties to the exudates of the weed, in this case annual ryegrass. It is not known whether the strongly allelopathic varieties also have strong tolerance of the ryegrass allelochemicals. Logic suggests that the most useful varieties are likely to be those with strong allelopathy and with strong tolerance to the allelopathy of their competitors. Unfortunately we do not know the answers because of the long history of breeding cultivars under weed free conditions – thus a long line of crop varieties that are totally reliant on herbicides for control of their competitors. This is an unsustainable paradigm in a world where the prospect of new herbicide modes of action is rare.

Is resistance likely with allelopathic varieties?

One of the key factors driving the interest in allelopathic varieties is herbicide resistance. Allelopathy is also a chemical option, albeit a natural chemistry one. If misused then resistance might be expected to evolve as for synthetic chemicals. There will be differences however in that allelopathy is usually a chemical mix of many chemicals presumably with different modes of activity and that may reduce the rate at which the buildup occurs. The important aspects here are that there is no panacea and that allelopathy needs careful management as with other weed management options. Whether a range of cultivars with different allelochemistries can be developed rests with investment of R&D.

Conclusions

Alternative options to herbicides need to be found if conservation agriculture is to be sustained. Allelpathy is one such alternative. There is now strong evidence that it occurs and that potency exists in commercial cutivars of several crops. There is a strong genetic base that suggests that allelopathic capability can be bred for in new varieties. However it needs to be considered in a multi-directional framework where the tolerance of the variety to the weed's allelopathic challenge may be as important as the crop variety's allelopathic potency towards the weed. Continued breeding of varieties under weed free conditions will perpetuate the strong dependence on synthetic herbicides that are currently threatend by weed resistance.

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Flaxleaf fleabane management in cropping systems of southern Australia

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Abstract
Flaxleaf fleabane (*C. bonariensis* (L.) Cronq.) has emerged as a difficult to control weed in southern Australia. Germination of fleabane in South Australia (SA) occurred between late August and early November, which is much later than that reported from southern QLD and NSW. Later germination of fleabane in SA means that is often not detected until after the crop has been harvested. Controlling fleabane in summer fallow has proven difficult with herbicide rates commonly used for weed control in summer fallow. Use of a double herbicide knock with glyphosate followed by paraquat has given consistently high levels of control where the first herbicide knock provided > 60% control by itself. High rates of glyphosate provided the greatest level of fleabane control, which is contrary to some results from the eastern states where glyphosate resistance is more common. Effective control of fleabane at two field sites during the summer fallow of 2012 conserved 45-71 mm soil water. As spring rainfall is becoming more erratic in southern Australia, it is extremely important to conserve soil water from summer rains by effectively controlling fleabane and other summer weeds.

Key words
Flaxleaf fleabane, summer fallow, weed management

Introduction
Flaxleaf fleabane (*C. bonariensis* (L.) Cronq.) has been a problematic weed in southern Queensland and northern New South Wales cropping regions for some time (Wu et al 2010). Over the last 10 years, it has emerged as a difficult to control weed in South Australia, Western Australia and Victoria. Fleabane has small seeds which germinate and establish close to the soil surface. Therefore, fleabane incidence tends to increase in no-till farming systems. Deep burial of seeds with cultivation maybe seen as a possible control option, however these seeds can remain viable, only to germinate when returned to the surface with later tillage (Wu et al 2007).

Fleabane is capable of large seed production with individual plants being able to produce up to 120,000 seeds (Wu et al 2007). These small light weight seeds can easily be dispersed over large areas by strong winds and water runoff assisted by a pappus on the seed, similar to sow thistle. Managing the seedbank of fleabane can be difficult as adjacent areas (i.e. neighbouring paddocks, roadsides and other non-cropped areas) are often a continual source for replenishment (Dauer et al 2007). As a result of high trichome density on the leaf surface, a thick cuticle and low stomatal density, fleabane has a natural tolerance to herbicide uptake (Procopio et al 2003). In addition control is made even more difficult as plants are often targeted after crop harvest by which time they have developed a large root system and spray conditions are often unsuitable for herbicide absorption.

The ecology of fleabane has been studied in the eastern states where it was found to have no innate dormancy and germination was mostly light and temperature dependant. Germination was shown to occur at temperatures between 10-25°C, however 20°C is optimal (Wu et al 2007). In eastern Australia 99% of fleabane plants emerge in late autumn, early and late winter, with less than 1% emerging mid spring (Wu et al 2007). This paper discusses the emergence pattern of fleabane in South Australia and its management in summer fallow.

Methods
Fleabane emergence
Fleabane emergence was monitored during 2012 in pots placed in the field at Roseworthy Campus, South Australia. Fleabane seed, collected in March 2012 from Bute SA, was spread on the surface of six trays of potting mix on 17 July and monitored until 14 December 2012, where moisture was not limiting. Fleabane census occurred regularly where plants were counted and removed.

Field trials

Two field trials were conducted in early 2012, investigating fleabane management in summer fallow, the first at Bute on northern Yorke Peninsula and the second at Pinnaroo in South Australia's eastern Mallee region (Table 1.). The trials evaluated several herbicide mixtures with and without a second knock of paraquat. A knife roller was also evaluated. All treatments were replicated three times. Soil moisture, to a depth of 1.2m, was assessed in April 2012 at the end of summer fallow prior to subsequent crop being sown.

Results

South Australian fleabane was found to emerge as late as August to November, when moisture was not limiting (Fig. 1). Fleabane seedling emergence continued at a steady rate until the end of October.

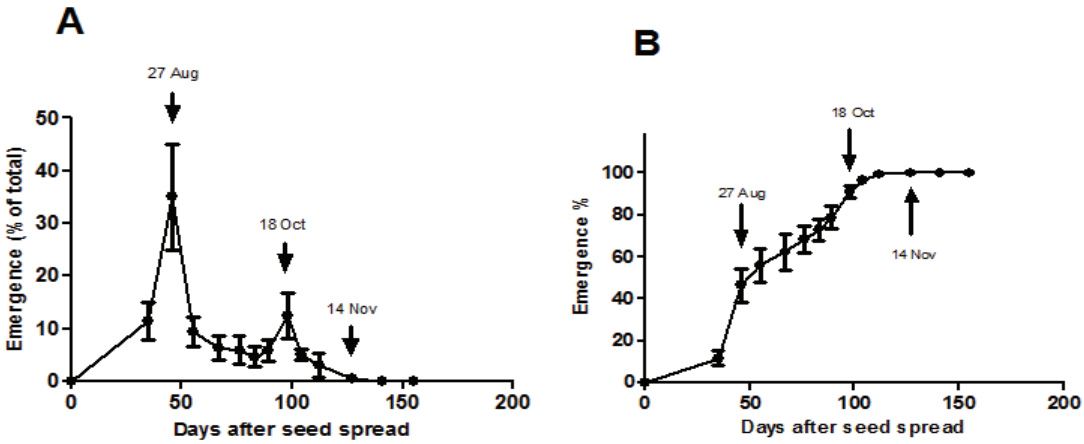

Figure 1. (A) Fleabane establishment in a pot study at Roseworthy starting from 17th of July 2012 when seed was spread. (B) demonstrates cumulative fleabane establishment as a percentage of total.

The 15 herbicide 1st knock treatments provided between 29 and 93% control of fleabane in summer fallow, which increased to 45-97% with the addition of the second knock of paraquat (Table 1). High levels (>90%) of fleabane control was achieved with glyphosate + 2,4-D amine + metsulfuron, or glyphosate + dicamba, or glyphosate + 2,4-D amine & picloram, when the second knock of paraquat was used. However, lower rates of glyphosate alone, glyphosate + clopyralid, or glyphosate + either carfentrazone or saflufenacil, gave inadequate weed control (<70%) even with the second knock (Table 1). High rates of glyphosate alone (≥3L/ha) provided good weed control even when the second knock was not used (Fig. 2A). Application of paraquat as a second knock was only effective when the initial herbicide application provided ≥60% control of fleabane (Fig. 2B). The use of a knife roller on the fleabane prior to first herbicide application provided no additional fleabane control (data not presented).

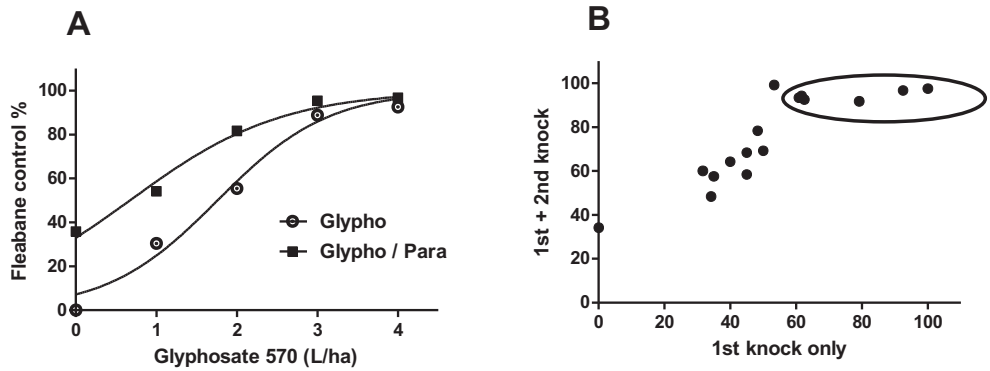

Figure 2. The response of fleabane to glyphosate alone and with additional application of 2.4L of paraquat (2nd knock) (A). (B) fleabane control of standalone herbicide treatment (1st knock) against control from both 1st and 2nd knock for each treatment across Bute and Pinnaroo trials.

Table 1. Effect of herbicide treatments on fleabane control from the final assessment (mid April 2012) for main herbicide treatment alone (1st knock) and with the addition of a subsequent paraquat application (+ 2nd knock). Data was pooled from Bute and Pinnaroo sites. Bute site: 1st knock 12 Jan, 2nd knock 9 Feb; Pinnaroo: 1st knock 1 Feb, 2nd knock 16 Feb.

Herbicide Treatment	**Fleabane control %**	
	1st knock alone	+ 2nd knock
Untreated	0	36
Glyphosate (570g/L) @ 1L / ha	30	54
Glyphosate (570g/L) @ 2L /ha	55	82
Glyphosate (570g/L) @ 3L / ha	89	95
Glyphosate (570g/L) @ 4L /ha *	93	97
Glyphosate (570g/L) @ 1L + 2,4-D amine (700g/L) @ 1.1L / ha	50	87
Glyphosate (570g/L) @ 1L + 2,4-D amine (700g/L) @ 1.1L / ha	50	84 **
Glyphosate (570g/L) @ 1L + Metsulfuron (600g/kg) @ 5g / ha	50	73
Glyphosate (570g/L) @ 1L + 2,4-D amine (700g/L) @ 1.1L + Metsulfuron (600g/kg) @ 5g / ha	57	91
Glyphosate (570g/L) @ 1L + Amitrole (250g/L) @ 2.8L / ha	63	80
Glyphosate (570g/L) @ 1L + Dicamba (500g/L) @ 0.5L / ha	46	69
Glyphosate (570g/L) @ 1L + Dicamba (500g/L) @ 1L / ha	58	91
Glyphosate (570g/L) @ 1L + Carfentrazone (400g/L) @ 45mL / ha	32	53
Glyphosate (570g/L) @ 1 L + Saflufenacil (700g/L) @ 18g / ha ***	29	45
Glyphosate (570g/L) @ 1L + 2,4-D amine & Picloram (300g/L & 75g/L) @ 0.7L / ha	50	97
Glyphosate (570g/L) @ 1L + Clopyralid (300g/L) @ 0.3L / ha	42	69
P<0.001 LSD = 10.934		

2nd knock herbicide application was Paraquat (250g/L)@ 2.4L / ha. The surfactant LI 700 @ 300mL / ha was used with all herbicide treatments except where indicated.

* Only at Bute site, ** 2nd knock was Fluroxypyr (400g) @ 400mL / ha, *** Bonza surfactant used instead of LI 700

The above treatments are for research purposes and some may not be registered

The best performing herbicide treatments provided significant gains in retained soil moisture compared to the untreated control, with 45 and 71mm of soil moisture retained for Bute and Pinnaroo, respectively (Fig. 3).

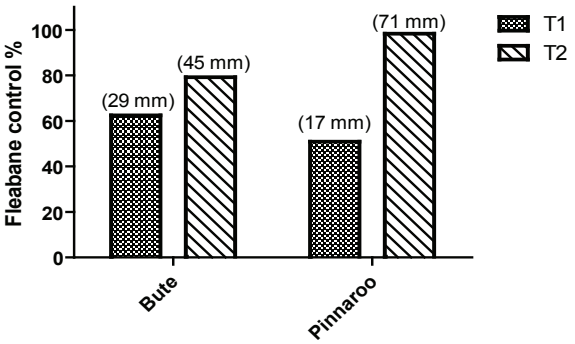

Figure 3. Fleabane control (%) at each site is displayed in the columns. Where T1 = glyphosate + 2,4-D amine + metsulfuron; T2 = glyphosate (3L/ha) as standalone treatment. Soil moisture was measured to a depth of 1.2m. Figures in brackets represent increase in soil moisture relative to the untreated control.

Discussion

In South Australia fleabane emerges through the late winter to late spring, which is later than that reported from the eastern states (Wu et al 2007). This later establishment of fleabane reduces the available options of

in-crop selective herbicides and allows the fleabane to take advantage of the crop's diminishing canopy cover late in the season. Often small fleabane seedlings go unnoticed by growers until after harvest, by which time the weed is well established. This is why the research reported here focussed on controlling fleabane in the summer fallow. There is no doubt fleabane control during summer is much more difficult due to unfavourable spray conditions and larger more established plants than earlier in the season. Previous research has shown that herbicide efficacy on fleabane decreases as the plant matures (Wu et al 2008). Future research needs to investigate the use of in-crop residual herbicides, late selective herbicides and crop-topping options to control fleabane before plants become established and difficult to control.

Herbicide control of fleabane in summer fallow could be achieved where the first-knock herbicide provided >60% control and was followed by the second-knock. In contrast to research from the eastern states, glyphosate alone when used at effective rates (≥3L/ha) provided good weed control by itself. However, reliance on glyphosate alone for fleabane control is not recommended because of confirmation of glyphosate resistance in SA, NSW and Qld (Malone et al 2012). Still glyphosate appears to be a useful tool in managing fleabane in the summer fallow. Increase in soil water from fleabane control over summer can significantly improve grain yields of winter crops.

Conclusion

The prevalence of fleabane appears to have steadily increased in many cropping districts in SA. Herbicide control of fleabane is difficult because it has a natural tolerance to herbicide uptake and plants usually have to be treated in summer when spray conditions are not favourable for herbicide activity. Field trials showed that fleabane control was significantly improved by the second knock of paraquat when the first herbicide knock provided >60% weed control. In contrast to the findings of previous studies in the eastern states, glyphosate alone can provide good control of fleabane.

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The extent of herbicide resistance in Tasmanian wild radish populations

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Abstract
Weeds are one of the major limiting factors in cropping systems and the development of resistance to herbicides used for their control can result in increased cost and complexity in managing these weed populations. With a high proportion of wild radish populations in Western Australia resistant to herbicides, along with a lower proportion in southern New South Wales it could be expected that some Tasmanian populations would also be resistant even though herbicide resistance in Tasmanian ryegrass populations occurs at a lower frequency than many other regions of Australia. For this reason wild radish seed samples were collected as part of a field survey of Tasmanian cropping paddocks in January 2015 to determine the extent of herbicide resistance in a number of weed species. A total of 75 paddocks in Tasmania were visited just prior to harvest from which 25 wild radish samples were collected, the second most common weed behind ryegrass. The samples were screened between March and May 2015 to six herbicides (chlorsulfuron, imazamox/imazapyr, atrazine, diflufenican, 2,4-D amine and glyphosate). The results from the screening will be compared with results from surveys conducted in Western Australia and southern New South Wales and the reasons for differences discussed.

Key words
2,4-D amine, chlorsulfuron, *Raphanus raphanistrum*,

Introduction

Herbicide resistant weeds are a major problem in the cropping regions of Australia. The first case in Australia was reported in annual ryegrass (*Lolium rigidum* Gaud.) in 1980 (Heap and Knight 1982), since then resistance has been reported in many weeds in Australia (Heap 2015). The first cases of resistance in wild radish (*Raphanus raphanistrum* L.) were reported in 2001(Hashem, et al. 2001; Walsh, et al. 2001).

Random surveys across the Western Australian cropping region have reported high proportions of wild radish populations that are herbicide resistant. In a 1999 random survey 21% of wild radish populations were found to be resistant to chlorsulfuron (Walsh, et al. 2001). This had increased to 54% in a survey conducted in 2003 when populations were found to also be resistant to 2,4-D amine (60%), diflufenican (40%) and atrazine (15%) with only 17% of the wild radish populations susceptible to all four tested herbicides (Walsh, et al. 2007). Surveys of the south west slopes region of New South Wales in 2011 and 2012 found 14% of wild radish populations were resistant to chlorsulfuron and 10% were resistant to imazamox+imazapyr, with no populations resistant to any of the other tested herbicides (atrazine, diflufenican, 2,4-D amine and glyphosate) (Broster, et al. 2014).

The extent of herbicide resistance in Tasmania is much lower than found on mainland Australia with a survey of Tasmania in 2010 finding 18% of ryegrass resistant to diclofop-methyl and 24% resistant to chlorsulfuron (Broster, et al. 2012a). This is much lower than found in Western Australia (Owen, et al. 2014), New South Wales (Broster, et al. 2011b; Broster, et al. 2013) and most regions of South Australia and Victoria (Boutsalis, et al. 2012). Similar findings were also recorded for wild oats in Tasmania with 13% of populations resistant to diclofop-methyl (Broster, et al. 2012a), again much lower than in Western Australia (Owen and Powles 2009) and southern New South Wales (Broster, et al. 2011a; Broster, et al. 2013).

With the lower level of herbicide resistant ryegrass in Tasmania than on mainland Australia it could be expected that resistance in other species would also be lower. This paper reports on the first survey of the Tasmanian cropping region to determine the level of herbicide resistance in wild radish.

Materials and Methods

Cropping or improved pasture paddocks in Tasmania were surveyed in January 2015 prior to the commencement of harvest. Paddocks were randomly selected at 10 km intervals, alternating left and right hand side of the survey transect where possible. The paddocks were surveyed by two people walking across

them for a ten to fifteen minute period. This resulted in 75 paddock being sampled of which 24 contained wild radish in sufficient numbers to collect enough seed for resistance screening. Eight other paddocks contained wild radish at densities too low to collect enough seed. The location of all sites were recorded using a GPS unit and the type of crop or pasture and all weed species present recorded with the density of any other weed species estimated.

Resistance screening

The 24 samples were sown in March 2015 with approximately 25 seeds placed in each pot. Two weeks after sowing all samples were counted. Pots were kept in a temperature controlled glasshouse (10°C minimum, 25°C maximum) and watered and fertilised as required. Where possible three replicates were sown, however as some samples had low seed numbers not all were able to be sown with three replicates or to all herbicides.

The samples were screened with six post-emergent herbicides across Groups B (chlorsulfuron and imazamox/imazapyr), C (atrazine), F (diflufenican), I (2.4-D amine) and M (glyphosate). All herbicides were applied when the plants were at the growth stage and rate recommended by the herbicide label (Table 1). The herbicides were applied using an automated laboratory-sized cabinet sprayer with a two nozzle moving boom, applying a water volume of 84 L/ha equivalent at 250 kPa. Adjuvants were added to herbicides as specified by label requirement. A standard susceptible biotype and a known resistant biotype, where available, were included with each cohort of samples.

Table 1: Herbicides and rates used for resistance screening (adjuvants were added as per label instructions).

Herbicide	Group	Rate (g a.i./ha)
chlorsulfuron	B (SU)	15
imazamox/imazapyr	B (imi)	16.5/7.5
atrazine	C	1000
diflufenican	F	100
2,4-D amine	I	875
glyphosate	M	648

Herbicide evaluation

All samples were assessed 28 days after treatment. Seedlings were counted before and after treatment to enable survival percentages to be calculated. Samples were classified as resistant if the mean survival percentage was greater than 20% for post-emergent herbicides while samples with survival percentages of between 10 and 19% were classified as developing resistance. The samples were categorised into respective Australian Bureau of Statistics Local Government Areas (LGA) and results were then compared between the regions (Australian Bureau of Statistics 2015).

Results

Of the 24 wild radish populations, all were screened to chlorsulfuron and two were classed as resistant. Due to low seed availability only 19 of the samples (including both chlorsulfuron resistant samples) were screened to imazamox/imazapyr, however six were classed as resistant and one as developing resistance (Table 2). One sample was resistant to both herbicides but the others were only resistant to one herbicide.

Two samples were resistant to 2,4-D amine and two were developing resistance. One of the resistant samples was resistant to chlorsulfuron but susceptible to imazamox/imazapyr while the other was susceptible to both Group B herbicides (Table 2). Both the samples developing resistance to 2,4-D amine were resistant to imazamox/imazapyr and susceptible to chlorsulfuron. None of the samples were classed as resistant or developing resistance to the other screened herbicides, atrazine, difluflenican or glyphosate (Table 2).

The 75 paddocks visited during this survey contained 13 different crop types of which wild radish was collected from seven. Wheat was the major crop sampled comprising 39 of the 75 visited paddocks and also the major source of the wild radish samples providing 16 samples. Other crops from which wild radish samples were collected were alkaloid poppies (4 samples from 4 paddocks), field peas (3/3), pyrethrum (3/4), barley (3/10), potatoes (1/2), forage rape (1/1) and clover pasture (1/4). Crops visited that contained

no wild radish included lucerne, oats and carrots (each 2 paddocks) and triticale and onions (1 each). Five of the samples from wheat crops and all three from barley crops provided insufficient seed for resistance screening.

Table 2: Wild radish resistance levels for the screened herbicides (Res – resistant; DR – developing resistance; TR – total resistant = resistant and developing resistance combined).

Herbicide	Tested (no.)	Res (no.)	DR (no.)	**TR (%)**
chlorsulfuron	24	2	0	**8**
imazamox/imazapyr	19	6	1	**37**
atrazine	20	0	0	**0**
diflufenican	21	0	0	**0**
2,4-D amine	23	2	2	**17**
glyphosate	19	0	0	**0**

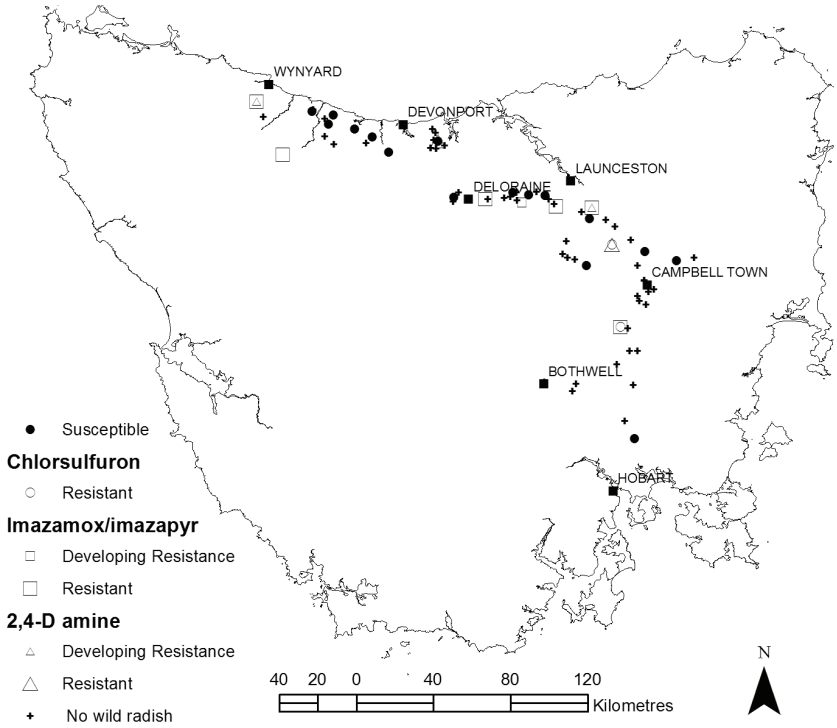

Figure 1: Map showing paddocks visited, wild radish locations and resistance status of wild radish

Discussion

Resistance was found to three herbicides in this survey, chlorsulfuron, imazamox/imazapyr and 2,4-D amine. The extent of resistance to chlorsulfuron was significantly lower than in Western Australia where 54% of samples were resistant and slightly lower than the 14% resistant found in southern New South Wales, however, resistance to imazamox/imazapyr was much higher in this survey than in southern New South Wales (37% cf. 20%) (Broster, et al. 2014; Walsh, et al. 2007). While no resistance to herbicides other than Group B was found in New South Wales, in Tasmania resistance was also found to a Group I (2,4-D amine) herbicide, albeit at an extent much lower than reported from Western Australia, 17% cf. 60% (Broster, et al. 2014; Walsh, et al. 2007).

The majority of the wild radish populations were found in the northern part of the surveyed region and at a higher proportion of paddocks visited. Only eight samples came from the Southern Midlands, Northern Midlands and Central Highlands LGAs from the 34 paddocks (24%) visited in these LGAs. Nine samples came from 23 visited paddocks (39%) in north coast LGAs (Waratah/Wynyard, Burnie, Central Coast, Kentish and Latrobe) while seven of the 18 paddocks (39%) visited in the Meander Valley contained wild radish. This higher prevalence of wild radish in the north of the surveyed area relative to the south was also noted when Tasmania was last surveyed for resistance to the grass weeds (J. Broster pers. obs.).

This could be the result of the different crops grown in the northern region to the Northern and Southern Midlands LGAs. In both the Northern and Southern Midlands LGAs the ratios of cereal crops to both vegetables and non-cereal broadacre crops were well above 1:1 compared with the north west region of the survey (Burnie, Central Coast, Kentish, Latrobe and Waratah/Wynyard LGA) where the ratios are below 0.25:1 (Broster, et al. 2012a). Crops such as pulses are less competitive than cereals and broadleaf weeds are also harder to control in these crops. That none of the barley or oat crops and less than 30% of the wheat crops visited provided sufficient wild radish seeds for resistance screening compared to all of the alkaloid poppy and pea crops and three of four pyrethrum crops supports this suggestion.

While this survey shows that the extent of resistance in wild radish is lower than in Western Australia, it is still significant. Resistance was present in two herbicide groups and wild radish was found in 43% of paddocks compared with New South Wales where wild radish was found in less than 10% of paddocks and resistant to only one herbicide group (Broster, et al. 2014; Broster, et al. 2012b). This suggests that in Tasmania the control of wild radish is of major importance and care needs to be taken to reduce the rate at which resistance develops further complicating wild radish control in the vast range of crops grown in Tasmania.

Acknowledgements
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A quick test for glyphosate resistance in annual ryegrass

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Abstract
Annual ryegrass is the most economically damaging winter crop weed in Australia. Effective control measures are key to minimising management costs and yield loss. Glyphosate is an effective herbicide used in post-emergent control of annual ryegrass, although continuous use has led to the evolution of herbicide resistance. Early and rapid identification of resistant plants facilitates control measures for resistant populations and helps minimise their spread. Some methodologies have been developed for the quick testing of glyphosate resistance in *Lolium* spp. The aim of this study was to assess a further methodology, using un-germinated and pre-germinated seed, for speed, simplicity and accuracy in determining phenotype. Four biotypes of annual ryegrass, two glyphosate resistant and two susceptible, were selected to evaluate the capability of the test to segregate between resistant and susceptible populations. The performance of the pre-germinated assay was compared with an assay using un-germinated seed. Seeds were placed on filter paper within Petri dishes containing glyphosate concentrations of 0, 2.5, 10 and 40 mg ae/L. Dishes were then placed in a growth incubator. After 7 days, root lengths were measured. Both assays were able to differentiate between resistant and susceptible biotypes. Differences in root length inhibition were greatest amongst samples with lower concentrations of glyphosate, with 2.5mg ae/L providing the greatest segregation for un-germinated seed (43% inhibition for susceptible versus resistant biotypes). The higher dosage of 10mg ae/L provided greater phenotype discrimination in pre-germinated seed (61% inhibition for susceptible versus resistant biotypes). Both pre-germinated and un-germinated seed assays provided a quick and simple method to identify glyphosate resistance in annual ryegrass.

Key words
Herbicide resistance testing, *Lolium rigidum*

Introduction
Herbicide resistance in annual ryegrass (*Lolium rigidum*) is an ongoing agricultural challenge, the species having already evolved resistance to 11 different groups and sub-groups of herbicides (Heap, 2014). The rapid adaptation of ryegrass ensures that we too must adapt in order to maintain effective weed management and long term control. Herbicide resistance testing plays a vital part in ryegrass and herbicide management, helping to determine whether errant ryegrass plants are herbicide survivors or application escapees. The most common methods for herbicide resistance testing involve variations of testing seed or pre-grown tillers in either glasshouse trials or laboratory based assays. Both have advantages and short comings: glasshouse trials are considered to be better representation of field conditions but are resource intensive; laboratory assays (Petri dish, enzymatic determination etc.) are generally faster, but can require extensive expertise and/or costly equipment.

Previous studies have evaluated herbicide resistance assays with simple Petri dish methods for glyphosate, an economically important herbicide, on *Lolium spp*. (Ghanizadeh, Harrington, James, & Woolley, 2014; Neve, Sadler, & Powles, 2004) using un-germinated seed in various media and concentrations. This study evaluated resistance testing annual ryegrass biotypes with both un-germinated and pre-germinated seed on filter paper.

Method and materials:
Annual ryegrass biotypes were selected from Charles Sturt University herbicide resistance testing service seed collection. Four biotypes, two with known glyphosate resistance history and two with known susceptibility were selected. Two assay methods were trialled, using pre-germinated and un-germinated seed.

Un-germinated seed
The surface of the seed was sterilised using a modified version of the procedure used by Sauer (Sauer & Burroughs, 1986). Seed was fully immersed in a 2% bleach solution for 2 min before thoroughly rinsing with deionised water and then dried in a laminar flow. This protocol limits interference from microorganism growth in the bioassay. Ten seeds from each biotype were selected and placed within 90mm plastic Petri dishes lined with filter paper (Advantech No. 2). A concentration range was selected that would capture a discriminating dosage of glyphosate. A similar test on Italian and perennial ryegrass used a dosage range of 0 to 320mg ae/L although differing concentration ranges were used for resistant and susceptible populations (0-320 mg ae/L and 0-40mg ae/L, respectively)(Ghanizadeh, et al., 2014). Adhering to the aim of developing a cheap and simple test, one concentration was range (0- 40mg ae/L) was tested. Four mL of glyphosate solution (0, 2.5, 10 and 40mg ae /L) were applied directly to the filter paper. Each treatment was replicated 4 times and dishes arranged in a randomised block design. Petri dishes were sealed with parafilm and stored in a growth chamber (12hr 15/25°C and day/night cycle). Root length was measured after seven days.

Pre-germinated seed
Pre-germinated seed was treated in the same manner as un-germinated seed, undergoing surface sterilisation and drying before being transferred to a Petri dish lined with filter paper. Four mL of deionised water were added to each Petri dish before being sealed with parafilm and placed in a growth incubator (12hr 15/25°C and day/night cycle) for 5 days. Once germinated, the assay was repeated in the same manner as for the un-germinated seed.

Results
Un-germinated assay
Root length was measured and calculated as a percentage of the growth of the control. All biotypes experienced greater root length inhibition as glyphosate dosage increased. An exception to this is the response of the resistant biotypes, which had an increase of root length at 2.5mg ae/L. This response may be the results of hormesis, an effect common in sub-lethal herbicide application (Belz & Duke, 2014). The two resistant biotypes had root lengths inhibited the least of the four biotypes tested. The most informative dosage (dosage that provided the greatest difference in root inhibition) was 2.5mg ae/L (Figure 1A). At this dosage, there is 43% difference in root inhibition between resistant and susceptible biotypes.

Pre-germinated assay
Root length inhibition was calculated in the same manner as the un-germinated assay. Resistant biotypes had the lowest amount of root inhibition of the four biotypes tested. The greatest difference in root inhibition between resistant and susceptible biotypes was at 10 mg ae/L glyphosate (Figure 1B). At this dosage, there is 61% difference in root inhibition between resistant and susceptible biotypes.

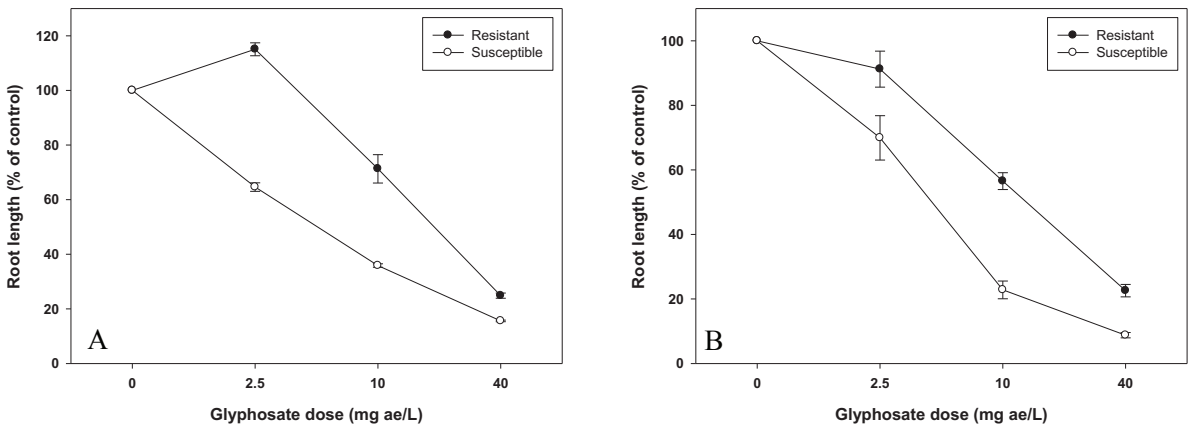

Figure 1: Effect of glyphosate concentration on root length inhibition (as percentage of control). Resistant biotypes were inhibited less than susceptible, A) Un-germinated seed assay, greatest difference between biotypes at 2.5mg ae /L. B) Pre-germinated seed assay, greatest difference between biotypes at 10mg ae /L. Data are the means of biotypes with 4 replicates and 10 seeds per replicates, measured after 7 days, error bars are standard error of the mean.

Discussion

This study set out to determine whether a simple Petri dish assay could provide a quick, simple, cheap, accurate and more informative method of herbicide resistance testing on annual ryegrass using pre-germinated seed. Biotype root inhibition was assessed across four biotypes with known resistance or susceptibility to glyphosate with two assay methods. Differences between biotypes of the same phenotype were not significant ($P>0.05$) and so data were arranged as the mean of the two biotypes. Previously reported resistant biotypes displayed less inhibition of root length than susceptible biotypes in both assays. Susceptible biotypes were more sensitive at low to midrange concentrations of glyphosate in both assays, providing a greater root length differential between phenotypes. A significant difference between resistant and susceptible biotypes was found for both assays ($P<0.05$). Un-germinated seed showed greater phenotype separation at 2.5 mg ae/L dosage with a 43% difference in root inhibition, whereas the higher dosage 10mg ae/L provided greater difference in pre-germinated seed with 61% difference in root inhibition between resistant and susceptible biotypes. An analysis of variance between both assays showed that there was no significant difference of root inhibition between biotypes in un-germinated and pre-germinated assays although it is likely that seed is more vulnerable to the inhibitory effects of glyphosate at the earlier growth stage in the un-germinated seed due to a decreased metabolic rate, resulting in a more pronounced effect at the lower dose. The observed hormesis response in the resistant biotypes in the un-germinated assay may be due to the earlier exposure of a biotype with resistance mechanisms triggered at this low dose responding more robustly than a more developed organism.

Each of the methods trialled had inexpensive materials and labour costs, totalling approximately $40 per biotype, and was completed in 1-2 weeks. This is significantly cheaper than the cost of glasshouse trials which can be in excess of $200, and required few specialised equipment or training. Conventional glasshouse trials do provide an accurate assessment of resistance representative of field conditions, and have the ability to test additional herbicides and different application methods. For a particular herbicide such a test may prove valuable for earlier diagnosis. Further refinement of methodology and additional testing would assess the veracity of these results.

Conclusion

Two seed assays were trialed for detection of glyphosate resistance in annual ryegrass. Both methods were able to segregate biotypes into their respective phenotypes consistent with glasshouse trials. Overall each assay method provided accurate results about individual biotype herbicide tolerance, although additional testing is required. Each method offers a cheap, low tech and simple test for glyphosate resistance.

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On-farm demonstrations of low-input methods for establishing legumes in central Queensland

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Abstract
In 2010 a three year Meat and Livestock Australia funded Producer Demonstration Site (PDS) was established to demonstrate low-input sowing strategies for achieving legume establishment in buffel grass (Pennisetum ciliare) pastures in central Queensland. Butterfly pea (Clitoria ternatea), burgundy bean (Macroptillium bracteatum) and siratro (Macroptillium atropurpureum cv. siratro and cv. Aztec atro) were sown by broadcast, direct drill and crocodile seeder methods. Intensive herd impact applied immediately post sowing was trialled to determine if seed germination and establishment would benefit from animal induced soil disturbance. Treatments with soil disturbance at sowing (direct drill and crocodile seeder) recorded higher first year legume numbers than broadcasting. Despite excellent rainfall in the first two years of the trial, strong population declines across all treatments were recorded in subsequent years, with similar plant populations per hectare recorded between treatments at the conclusion of the trial. The results from the application of herd impact were inconclusive. Siratro was the only species to persist within the buffel grass dominated pastures. This trial demonstrated that low-input sowing methods with little or no removal of grass competition achieved poor plant populations. Industry needs to adopt longer fallow management for moisture storage and control of grass when establishing legumes into existing grass pastures.

Key words
Nitrogen, fixation, agronomy, grazing, buffel grass, yield

Introduction
Declining sown pasture productivity as a result of reductions in plant available soil nitrogen is an ongoing constraint to grazing production across the brigalow bioregion of central and southern Queensland (Peck et al. 2011). Research suggests that legume establishment offers the most cost effective long-term remediation strategy for improving pasture quality and yield (Peck et al. 2011). In 2010, a three year Meat and Livestock Australia funded Producer Demonstration Site (PDS) was established to demonstrate low-input sowing strategies for achieving legume establishment in buffel grass pastures in central Queensland.

Methods
Two uniform and adjacent 50 hectare paddocks consisting of buffel grass dominated brigalow clay soils were selected on a beef cattle property in the Arcadia Valley, central Queensland. Within each paddock, five treatments were randomly allotted a ten hectare strip (Table 1). There were no dividing fences to distinguish the boundaries of the five treatments within each paddock.

The five treatments included:
- Control: no treatment.
- Broadcast: Seed applied using an air-driven, back-mounted pellet applicator.
- Broadcast near water: Ten hectare buffer zone to eliminate potential effects of higher utilisation. Seed applied using an air-driven, back mounted pellet applicator.
- Direct drill: Seed sown using converted chisel plough with narrow points spaced at 1.1m intervals.
- Crocodile seeder: A pulled implement consisting of two partially offset drums, each with multiple metal feet that cut into the soil surface, leaving a scalloped hole. Seed was deposited from the drums into each hole.

Table 1: Paddock and treatment layout of the trial. The northern boundary is located adjacent to the watering point (🪣)

Paddock 1 (50 ha) (herd impact applied at sowing)					Paddock 2 (50ha) (no herd impact applied at sowing)				
Direct Drill Seeder (10ha)	Crocodile Seeder (10ha)	Control (10 ha)	Broadcast (10 ha)	Broadcast Near Water (10 ha)	Broadcast Near Water (10 ha)	Control (10 ha)	Direct Drill Seeder (10 ha)	Broadcast (10 ha)	Crocodile Seeder (10 ha)

Three legume species consisting of butterfly pea (*Clitoria ternatea*), burgundy bean (*Macroptillium bracteatum*) and siratro (*Macroptillium atropurpureum* cv *sirarto* and *cv Aztec* atro) were sown as a combined mix in a single pass across the treatments (except control) in mid to late 2010. Seed sowing rates and viability are summarised in Table 2. All seeds were treated with the recommended rhizobial inoculants at time of sowing. Immediately prior to sowing, both paddocks were grazed down beyond regular end of dry season levels in an attempt to reduce the competitive effects of the existing buffel grass on seed germination and seedling growth. Paddock 1 had intensive herd impact applied by stocking 200 head of cattle (average weight 450kg) per hectare for 12 hours immediately following sowing. This was applied with the aim of improving soil-seed contact and further minimising pasture competition. Following the initial high density herd impact, each paddock was grazed using the same management regime for the remaining duration of the trial.

Legume plant populations were recorded annually at the end of each growing season. A minimum of forty (40) quadrats (0.25m^2) were assessed at approximately equal distances along two random transects between the northern and southern boundaries of each treatment. Due to the demonstrative nature of the trial and design, labour and cost constraints, results were not statistically analysed.

Table 2: Seeding rates applied within the trial and viability information (viability information provided by seed supplier).

	Butterfly pea (*Clitoria ternatea*)	**Burgundy bean (*Macroptillium bracteatum*)**	**Siratro (*Macroptillium atropurpureum*)**
Standard indicative seeds/kg	23,000	160,000	80,000
Measured viable seeds/kg	23,286	140,365	80,268
% Viable Seed	101	88	100
Sowing rate (kg/ha)	1.7	2	1.15

Results and discussion

Rainfall

Rainfall received in the first summer growing season of the trial was exceptional (Figure 1). Rainfall in the second summer was above average, while the final growing season recorded below average falls.

Total legumes

Observationally, in the first year, the direct drill and crocodile seeder treatments resulted in higher total legume emergence (Figure 2). This is likely to have been due to these treatments having increased levels of soil disturbance and soil-seed contact at sowing. By 2012, all treatments demonstrated a decline in legume populations, with the direct drill and crocodile seeder treatments maintaining higher legume numbers per hectare than both broadcast treatments. During the final year (2013), legume population levels declined even further from 2012 with little differences in final legume counts recorded between all treatments.

The rapid decline in plant population counts was expected given the competitive conditions of established pastures and the sowing methods employed (Miller *et al*. 1993). In comparison to more intensive seedbed preparation methods such as full cultivation and/or herbicide control, all of the Producer Demonstration Site sowing methods were relatively low-input and resulted in little or no removal of grass competition. The direct drill and crocodile seeder approaches, while providing better soil-seed contact did not reduce grass competition. Broadcasting is inherently low-input and does nothing to aid in the optimal placement of seed within the soil, relying heavily on favourable seasonal conditions for any prospect of establishment success.

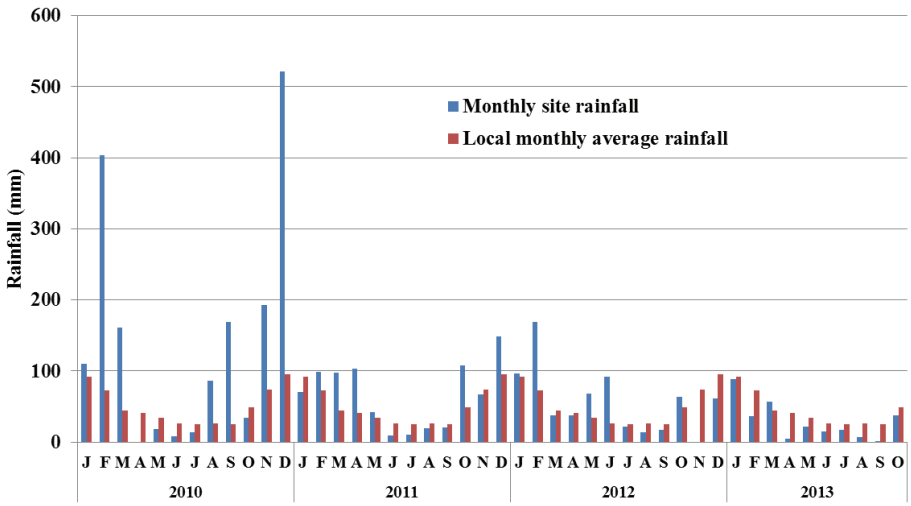

Figure 1: Monthly site rainfall for the duration of trial (mm). Rainfall in the first two summer growing seasons of the trial was well above average, while the third wet season was below average.

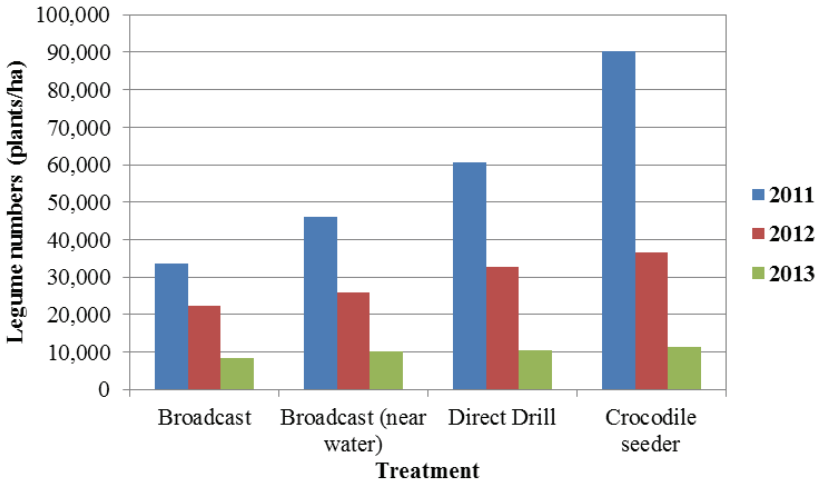

Figure 2: Average combined annual legume population counts for all species (plants per hectare) for each of the four treatments within the trial.

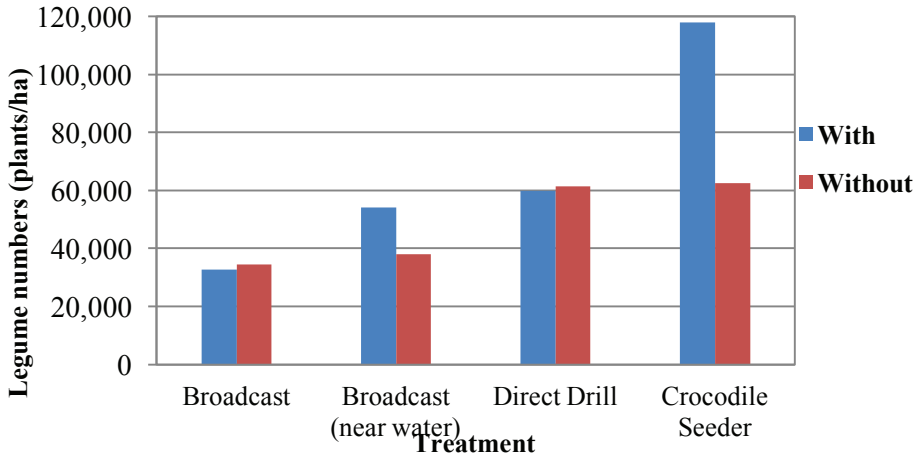

Figure 3: Average combined legume population counts for all species (plants per hectare) in April 2011 following 'with' and 'without' herd impact at sowing for each of the four treatments within the trial.

Individual legume species

Across all treatments, siratro was the most dominant and persistent legume species. Initial plant counts for burgundy bean and butterfly pea were on average lower than siratro for all treatments. Treatments with higher levels of soil disturbance did result in higher plant germination and establishment levels for

siratro and burgundy bean. Butterfly pea recorded similar plant populations for 2011 for both the broadcast treatments. From 2011 to 2012, plant attrition rates were severe for both burgundy bean and butterfly pea despite above average rainfall. In contrast, siratro demonstrated a smaller decline across all treatments. By 2013, both siratro and butterfly pea recorded little to no difference between treatments for each individual species with burgundy bean virtually non-existent at the conclusion of the trial.

Grazing and herd impact

The initial total legume population counts at the conclusion of the growing season in 2011 showed that the 'with' herd impact at sowing resulted in higher plant numbers for the broadcast near water and crocodile seeder treatments (Figure 3). The higher numbers in the crocodile seeder treatment appeared to have been influenced by several quadrats that recorded higher legume counts than the average quadrat figures for the treatment plot. When averaged across all treatments, the 'with' herd impact resulted in higher plant populations at the conclusion of the first growing season (Figure 3). There appeared to be no herd impact effect on the broadcast or direct drill treatments. No herd impact benefit was observed in subsequent years.

Conclusion and recommendations

Practices with greater soil disturbance and soil-seed contact at the time of sowing demonstrated increased first year legume counts when compared with broadcasting. Through significant rates of legume plant attrition recorded across all treatments, these gains however were lost within the subsequent two years of the trial despite above average rainfall. This rapid decline in legume plant populations was partly expected given the competitive conditions of established grass pasture and the low-input sowing methods employed. Siratro was the only species to persist within the buffel grass dominated pastures. There was an observed but inconclusive benefit from adopting intensive herd impact on legume emergence in the first growing season of the trial, but this was not observed in subsequent years. The trial demonstrated that low-input sowing methods with little or no removal of grass competition achieved poor plant populations. Industry needs to adopt longer fallow management for moisture storage and control of grass when establishing legumes into existing grass pastures.

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Influence of fungal endophyte on plant water status, non-structural carbohydrate content and biomass partitioning in *Brachiaria* grasses grown under drought stress

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Key words
Tropical forages, endophytes, symbiosis, plant physiological responses

Abstract
Fungal endophytes are known to improve drought resistance in plants, although mechanisms for such tolerance remain unknown. A greenhouse study was performed using five *Brachiaria* grass cultivars, cvs. (*B. decumbens* cv. Basilisk, *B. humidicola* cv. Tully, *B. brizantha* cv. Marandu, *Brachiaria* hybrids cv. Cayman and cv. Mulato II) to test the influence of fungal endophyte on plant water status (measured as relative water content of leaf), total non-structural carbohydrates (TNC) content and biomass partitioning. Results on the influence of endophyte infection in only two cultivars (cv. Cayman and cv. Tully) are presented. After 24 days of drought stress, endophyte infection significantly increased relative water content in cv. Cayman and cv. Tully by 20% and 8.4%, respectively and reduced leaf dry matter content by 17% and 8.9%, respectively ($p<0.05$). Under well-watered condition, the endophyte significantly reduced shoot and whole plant TNC in cv. Cayman by 19.3% and 15.5%, respectively relative to uninoculated plants ($p<0.05$). Furthermore, stem, root and total biomass in cv. Tully were reduced due to the endophyte by 10.3% ($p=0.046$), 18.5% ($p=0.006$) and 11.9% ($p=0.022$), respectively under drought stress.

Introduction

Forage grasses form symbiotic associations with fungal endophytes that confer protection to plants and make them more persistent under drought (Assuero *et al*. 2006). Endophytes produce metabolites including alkaloids, carbohydrates as well as amino acids like proline and glutamic acid (Nagabhyru *et. al*. 2013). Accumulation of these compounds influences host fitness and plant physiological responses to biotic and abiotic stresses. Studies on grass-endophyte symbiosis have been extensively conducted in temperate grasses, but there remain critical knowledge gaps on the role of endophytes in the performance of tropical forages. The objective of this study was to determine the effect of the endophyte, *Acremonium implicatum*, on leaf relative water content (RWC), leaf dry matter content (LDMC), total non-structural carbohydrates (TNC) content and biomass partitioning in five *Brachiaria* grass cultivars.

Materials and Methods

The study was conducted at the International Center for Tropical Agriculture, CIAT (Palmira, Colombia) using five *Brachiaria* cultivars (*B. decumbens* cv. Basilisk, *B. humidicola* cv. Tully, *B. brizantha* cv. Marandu, *Brachiaria* hybrids cv. Cayman and cv. Mulato II). A total of 100 plants (20 plants for each cultivar) were grown in transparent plastic cylinders of 7.5 cm diameter x 120 cm length for 54 days. The cylinders were filled with 8.5 kg soil at a 2:1 ratio of soil:sand, and fertilized according to the recommended fertilizer requirement for *Brachiaria* forage grasses (Rao *et al*. 1992). Four factorial treatment combinations were applied with five replicates for each treatment combination which included: endophyte-well-watered (E+_WW), endophyte-drought stress (E+_DS) and no endophyte-well-watered (E-_WW), no endophyte-drought stress (E-_DS). Half (50) of the plants were inoculated with solutions of the fungal endophyte, *Acremonium implicatum*, while the other half (50) left uninoculated. Plant water status was estimated by leaf RWC, which was determined according to equation (i) by cutting leaf discs from five tillers and rehydrating in water-filled petri dishes for 48 hours at 4 oC; while LDMC was determined according to equation (ii).

$$\text{RWC (\%)} = \frac{(Lfw-Ldw)}{(Ltw-Ldw)} \times 100 \quad \text{(i)}$$

$$\text{LDMC (mg/g FW)} = \frac{[Ldw]}{[Lfw]} \quad \text{(ii)}$$

Where *Lfw* = Leaf disc fresh weight; *Ltw* = Leaf disc turgid weight; *Ldw* = Leaf disc dry weight; FW = Fresh weight.

Plant tissues were oven-dried at 60 oC for 72 hours. Dry weight of the leaf discs (Ldw), as well as leaf, stem and root biomass was determined. Dry tissues were ground into powder and tissue TNC content was determined according to a modified method of Kang and Brink (1995).

Results and discussion

Although influence of endophyte was tested in five *Brachiaria* cultivars, results for only two cultivars (Cayman and Tully) with a total of 40 plants are presented here. Average results of RWC and LDMC values obtained from five sample replicates (Figs. 1 & 2) revealed that endophyte significantly increased RWC in cv. Tully and cv. Cayman under drought stress by 20% [$p<0.0001$] and 8.4% [$p=0.013$], respectively. At the same time, the endophyte reduced LDMC in cvs. Tully and Cayman by 17% (339 to 239 mg/g FW) [$p<0.0001$] and 8.9% (301 to 252 mg/g FW) [$p=0.0001$], respectively when compared with E- plants. Under well-watered condition, endophyte reduced shoot and whole plant TNC by 19.3% (119 to 80.5 mg/g of shoot biomass) [$p<0.0001$] and 15.5% (132.7 to 97 mg/g of total biomass) [$p=0.007$], respectively. Furthermore, endophyte infection reduced stem and root biomass in cv. Tully under drought stress by 10.3% (6.20 to 5.04 g) [$p=0.046$] and 18.5% (4.01 to 2.76 g) [$p=0.006$], respectively and total plant biomass subsequently reduced in E+ plants by 11.9% (12.67 to 9.98 g) than in E- plants [$p=0.022$].

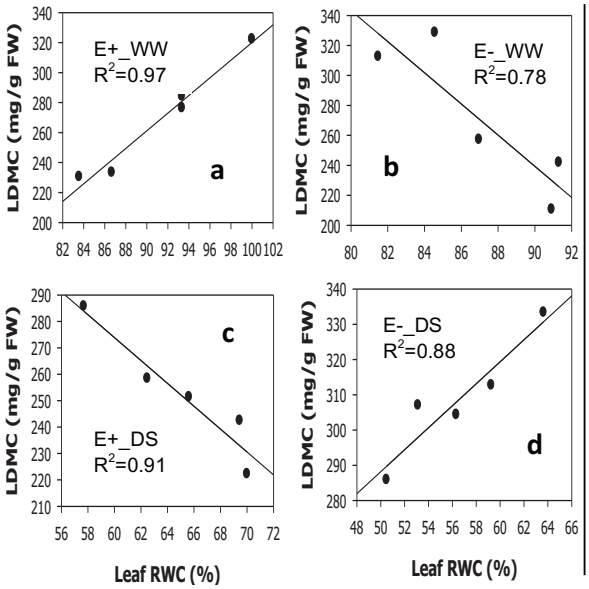

Figure 1. Relationships between RWC and LDMC in cv. Tully for E+ (a & c) and E- plants (b & d) under well-watered, WW (a & b) and drought stress, DS (c & d)

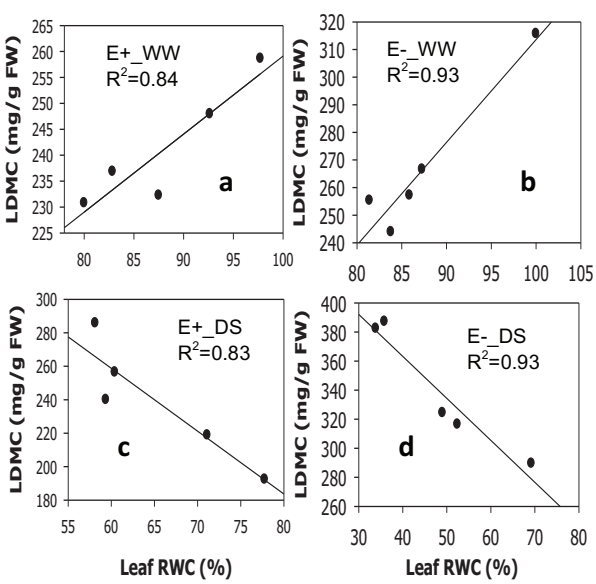

Figure 2. Relationships between RWC and LDMC in cv. Cayman for E+ (a & c) and E- plants (b & d) under well-watered, WW (a & b) and drought stress, DS (c & d)

*[Each of the five points on the graph is a sample replicate; average results are explained above]

Strong relationships were found between RWC and LDMC in both cultivars (R2=0.78 to 0.97) under well-watered and drought stress conditions (Fig. 1 & 2). Increase in RWC under well-watered condition was associated with increase in LDMC for E+ treatment contrary to E- treatment in cv. Tully. Under drought stress, LDMC decreased with increase in RWC under E+ treatment in contrast to E- treatment (Fig. 1). In Cayman (Fig. 2), increase in RWC under well-watered condition was associated with increased LDMC for both E+ and E- plants; while under drought stress, increase in RWC resulted in decrease in LDMC for both E+ and E- plants. Generally, overall trend showed that LDMC decreased as RWC increased under well-watered and drought condition (Result not shown).

Cultivars with greater resistance to drought usually maintain higher leaf RWC under drought stress (Matin *et al.* 1989) since higher RWC under water deficit may be associated with lower leaf transpiration and higher assimilation rate (Anyia and Herzog 2003). However, although cv. Tully maintained the highest leaf RWC

under drought stress (61%), it showed the least resistance to drought stress since it had the lowest LDMC, leaf TNC and lowest leaf biomass.

Conclusions

Despite detection of significant endophyte effect on plant water status (RWC of leaf), LDMC, TNC and biomass in at least two cultivars (cv. Tully and cv. Cayman), no substantial positive effect of the endophyte on plant growth was found. Although this study suggests that endophytes might improve plant water status by increase in leaf RWC, it also demonstrates that endophytes might encourage high carbon losses through tissue respiration leading to reduction in TNC contents and biomass in certain cultivars. Endophytic reduction of TNC content could also reduce forage quality in some cultivars.

Acknowledgement

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Broad NIRS calibrations to predict nutritional value of the southern feedbase

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Abstract
Near infrared reflectance spectroscopy (NIRS) is used to predict the nutritive characteristics of feeds consumed by livestock. Once calibration equations are developed between reflectance and measured nutritional traits, NIRS is rapid and inexpensive. Our aim was to develop broad NIRS calibrations for the southern feedbase of Australia. A total of 4385 samples from 154 accessions of 109 species of annual and perennial legumes, grasses and forbs were grown in common plots at two locations over 3 seasons. Plots were sampled across all growth stages. A quarter of these samples were subject to laboratory analysis of dry matter digestibility (DMD), total nitrogen (N), neutral detergent fibre (NDF), acid detergent fibre (ADF) and organic matter (OM). Of the samples analysed, half were used to develop the calibration and half were set aside for validation. Development of broad calibrations across the sample range was very successful despite the large variation in the taxonomy and life history of the samples. When predicting samples from the collection that were not included in equation development, the statistics of prediction were; total N - r^2 0.96, RPD (relative percent difference) 5.3, *in vitro* DMD - r^2 0.93, RPD 3.7, ADF - r^2 0.93, RPD 3.9 and NDF - r^2 0.95, RPD 4.3. When the validation samples were separated into taxonomic groups, the prediction errors were considerably lower for annual species than perennial species. The data generated is being used to compare nutritional value of species over time and investigate opportunities to improve productivity and reduce methane emissions intensity from sheep in southern Australia.

Key words
Feed testing, multispecies, pasture, forage, plant improvement

Introduction
NIRS is used by industry to predict the nutritional characteristics of feeds consumed by livestock. The method relies on the development of mathematical relationships between measured traits and light absorption properties in the NIR region (wavelength range 700 – 3000 nanometres). Once calibration equations are developed, NIRS is rapid, inexpensive, non-destructive and can predict a large range of traits at the same time (Deaville and Flinn 2000). It is therefore a powerful tool within forage improvement/breeding programs for identifying plant species and genotypes within species with superior nutritional traits. NIRS also allows industry to conduct rapid assessment of the nutritional value of feeds and pastures, therefore informing feed purchasing and grazing management decisions. By providing a tool to improve quality of the feedbase and influence management, NIRS calibrations can be used to improve productivity, profitability and possibly reduce methane emissions intensity from ruminant industries.

There have been a number of studies exploring how much taxonomic and/or nutritional diversity is required to develop robust calibrations. Shenk and Westerhaus (1993) found that if enough samples are utilised, broad multi-forage species calibrations can be nearly as accurate as those for single species. In southern Chile, a calibration was successfully developed for mixed swards, comprising 8 perennial grass and legume species (Lobos et al 2013). The aim of this project was to investigate the feasibility of developing broad NIRS calibrations for predicting nutritional value of the southern feedbase of Australia. Using samples from 109 forage species we tested the hypothesis that it would be possible to develop a global calibration across a diverse range of forage species.

Materials and methods
We utilised 4385 samples representing 154 accessions from 109 species of temperate forages. The accessions were grown in common garden plots at 2 locations (Urrbrae in South Australia and Brookton in

Western Australia). The diversity of the sample base included commercialised and experimental material, with 60 accessions of annual legumes, 30 accessions of perennial legume, 18 accessions of annual grasses, 25 accessions of perennial grasses, 12 accessions of annual forbs and 9 accessions of perennial forbs. To capture the possible diversity in nutritional profiles, plants were sampled across all growth stages (approximately every 3-6 weeks).

Sample growth, collection and processing

Each accession at each site was located in randomised plots (1 x 8 m) within 3 replicated experimental blocks. Annual legumes, annual grasses and forbs, perennial legumes and perennial grasses and fobs, were in separate but adjacent plots within the same paddock. Sowing rates, herbicides, fertilisers and inoculants (for legumes) were according to recommended best practice. At sampling, biomass was harvested from a new area within the plot, so it was not regenerating growth from a previous cut. Samples were collected between June 2012 and December 2014 and were either frozen and later freeze dried or placed in a paper bag then oven dried at 60°C. After drying, samples were ground to pass through a 1 mm screen using either a Cyclotech or Retsch Twister mill grinder. A preliminary study revealed that there was little bias associated with these grinders. Samples were then scanned by NIRS and throughout the project a subset was set aside for chemical analysis. Initially we selected a range of species and sampling times for analysis and then focussed on spectral gaps and outliers. Across the 3 year project a total of 1086 samples were subject to the full range of laboratory analyses.

NIRS scanning and mathematical treatments

Spectra were collected using a Unity Spectrastar 2500X- rotating top window system (Unity Scientific). The spectrum file data from the Spectrastar was converted to a multifile for the chemometric software package Ucal (Unity Scientific) used to generate predictions. Partial least squares regression was used to develop the calibrations. We tested a range of pretreatment options including standard normal variate detrending and derivatization with different derivative gap and smoothing. From this the best performing equations were selected. No wave specification trims were utilised and the entire available spectra from 680 nm to 2500 nm was employed. Outlier limits were left at default settings; T limit = 2.5, GD limit = 3.0 and neighbourhood size = 0.20. A dataset of 910 spectra with chemistry that included samples across all taxonomic groupings from both sites across seasons was used to develop the calibration presented in this paper. Approximately half the dataset (n=460) was used to develop the calibration and the remaining half for independent validation (n=450).

Assessing predictive ability

The performance of calibration equations was assessed using a number of criteria. Initially the r^2 value, 1-vr, SECV and RPD value. RPD tests the strength of the relationship between a constituents values and the error of the NIR predicted results and was calculated by $RPD = 1 / (1 - r^2)^{0.5}$. The larger the RPD value the greater the predictive ability of the calibration. We have adopted the guide of Williams (2014) who suggested RPD values of 0.0–1.9 are very poor and not recommended for forage testing; RPD values of 2.0–2.4 are only of use for rough screening; RPD values of 2.5–2.9 offer a fair screening potential; RPD values of 3.0–3.4 are good; RPD values of 3.5–4.0 are very good and RPD values of 4.1+ are deemed excellent.

Wet chemistry

In vitro DMD, adjusted to predict in vivo DMD, was determined in duplicate using a modified pepsin-cellulase technique described by Clarke et al. (1982). Modifications include different sample weight (600 mg), the use of ANKOM Technology F57 filter bags, sealed plastic boxes as incubation vessels and use of an orbital mixer incubator (set at 48°C and 2rpm). Duplicate samples of seven AFIA standards (AFIA 2007) with known in vivo DMD were included in each batch to allow raw laboratory values to be adjusted to predict *in vivo* DMD using linear regression (mean se across runs for standards was 0.261%). Concentrations of NDF and ADF of the material were measured sequentially, according to operating instructions, using an Ankom 200/220 Fibre Analyser (Ankom® Tech. Co., Fairport, NY, USA). Duplicate samples were analysed for each diet. An oaten hay QC sample was included in each of the 103 fibre analysis runs (NDF 30.19 ± 0.1137% DM and ADF 19.71 ± 0.0665% DM). Total ash was measured on duplicate samples according to the methods of Faichney and White (1983). Total N and C were determined by combustion using a Leco CN628 N Analyser (Sweeney and Rexroad 1987).

Results

Table 1 presents the performance statistics for the mature calibration. Total N was predicted with an RPD of 5.3, falling into the excellent category of Williams (2014). The mean error of prediction was 0.17% (equating to about 1% CP). Predictions of NDF were also excellent with an RPD of 4.3 and an error of 3.5% units. The ADF predictions were very good with an RPD of 3.9 and error of 2.1% units. DMD also fell into the very good category of Williams (2014) with an RPD of 3.7 and an error of 2.6% units. Predictions of OM were not as accurate with an RPD of 2.2 and an error of 0.85% units. We could not predict total C.

Table 1 Performance statistics of the mixed species NIRS calibrations

Trait	r^2	1-VR	SECV	RPD	r^2 (validation)	RPD (validation)
NDF	0.941	0.918	3.50	4.1	0.945	4.3
ADF	0.957	0.935	2.10	4.8	0.933	3.9
DMD	0.937	0.916	2.60	4.0	0.926	3.7
OM	0.905	0.851	0.02	3.2	0.794	2.2
N	0.977	0.967	0.17	6.6	0.964	5.3
C	0.713	0.634	0.71	1.9	0.495	1.4

Using the validation set, we investigated errors of prediction for each of the following groups; annual grasses, annual legumes, perennial grasses, perennial legumes and forbs. Table 2 presents the r^2 and RPD values derived from a regression of laboratory against predicted values. Across all groups, prediction of total N (thus crude protein) was excellent. The NIRS predictions were most accurate for the forbs, annual grasses and annual legumes. With the exception of OM, the RPD values indicate that we generated excellent predictions for these groups (RPD > 4.1). The calibration resulted in very good predictions of ADF and DMD for the perennial grasses but for NDF only yielded prediction that would be of value as a rough screening tool. For perennial legumes, ADF, DMD and OM predictions were very good but NDF was poor.

Table 2 Validation of global calibration with validation samples split into groups

Trait	Annual grasses		Annual legumes		Perennial grasses		Perennial legumes		Forbs	
	r^2	RPD	r^2	RPD	r^2	RPD	r^2	RPD	r^2	RPD
NDF	0.951	4.5	0.955	4.7	0.818	2.3	0.767	2.1	0.980	7.1
ADF	0.956	4.8	0.973	6.1	0.927	3.7	0.880	2.9	0.983	7.7
DMD	0.964	5.3	0.959	4.9	0.927	3.7	0.887	3.0	0.981	7.3
OM	0.920	3.5	0.907	3.3	0.790	2.2	0.930	3.8	0.880	2.9
N	0.986	8.5	0.980	7.1	0.987	8.8	0.966	5.4	0.984	7.9

Discussion

The data presented in this paper suggest that a large, robust NIRS calibration for estimating nutritional value of a broad range of samples from the southern feedbase of Australia is feasible. It is likely that these calibrations could be further improved by using a greater number of samples for calibration and less for validation. While the literature would suggest that increasing diversity leads to stronger calibrations (Shenk and Westerhaus, 1993), the diversity between species in this data set was much larger than others reported in the literature with inclusion of 109 species across a number of plant families. During the three year project, the accuracy of predictions from the calibrations declined after the first year as we increased the spatial and temporal diversity of the sample range with samples from the site in Western Australia and a second season in South Australia (data not presented). This highlights the need to include spatial and temporal diversity within the dataset if calibrations are to be used beyond the reference sample collection sites. If this calibration is to be developed further, we would seek to build spatial diversity by inclusion of the same species from other sites in southern Australia. We would also investigate ability to predict nutritional value of mixed swards.

These calibrations represent a useful tool for livestock industries in southern Australia as they are likely to encompass nearly all of the species that could appear in monocultures or mixed swards across all of their lifecycles. Inexpensive and rapid prediction of the nutritional value of pastures assists producers to optimise feed purchasing decisions, grazing management and growth rates of animals. This may lead to increased

profitability and reduced methane emissions intensity if animals reach slaughter weight faster with less feed inputs. For a subset of these samples, we have developed very good predictions of methane produced during batch culture fermentation.

Development of accurate calibrations can be very useful in plant development programs where large numbers of plants require assessment of their nutritional value. A recent study, where NIRS was used to predict the nutritional value of lucerne accessions within a breeding program, demonstrates this point. The team found significant variation between lucerne accessions for all traits and estimated M/D values of material at the same vegetative stage to range from 9.34 to 10.75 MJ ME/kg DM. Using the ruminant feeding model GrazFeed (Freer et al 1997), it was predicted that a pregnant Merino ewe (day 100 of gestation) offered the accession with the highest DMD would eat 1.2 kg of DM per day and grow at a rate of 210 g/week. In contrast the same ewe eating the accession with the lowest DMD would eat 0.97 kg of DM per day and lose 112 g/week. For mature, dry sheep, the difference in predicted weight gain was 3-fold (Norman et al 2013).

A critical factor leading to success of this work has been the quality of the laboratory data behind the calibration (Deaville and Flinn 2000). Not all differences between NIRS predictions and reference values can be ascribed to NIRS prediction error (Coates 2002) as the error sources of the reference method are incorporated into the model. By using a single, highly trained laboratory operator and adoption of a range of quality control samples, we managed to keep lab errors to a minimum (*in vitro* DMD 0.23%), NDF (0.11%) and ADF (0.7%). Our inability to develop good predictions for NDF in perennial legumes is an example of the importance of the quality of the reference data. Our variances between replicate samples during NDF measurement are larger for perennial legumes than for either annual legumes or annual grasses, suggesting a problem with the method we are using.

The current data set with over 1000 samples with matching scans and chemistry provides an excellent platform for future refinement, adoption of sample-specific PLS models or generation of calibrations for new nutritive traits. All reference samples from this study have been vacuum sealed and stored in dry conditions at 4°C to allow measurement of other nutritional traits of interest in the future. Ongoing research is investigating tradeoffs in the use of fresh and unground material with a view to using hand held ASD for near real-time estimation of nutritional traits and to reduce costs.

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Changes in rhizobia population over time in inoculated and uninoculated lucerne plants

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Abstract

Successful establishment of lucerne is dependent on the formation of effective nodules by the bacterium *Sinorhizobium meliloti*. Recently there has been some debate on whether addition of commercial inoculants is needed if the site has previously been sown in lucerne. The genotype of bacteria in the nodules of lucerne plants inoculated with the commercial inoculant and an uninoculated bare seed control was investigated over a three year period. In 2011, two months after sowing and again in 2014, three years after sowing, bacteria were recovered from the nodules of lucerne plants grown at a site with a previous lucerne history. In 2011, the 194 isolates collected across the inoculated and uninoculated treatments, produced 17 unique genotypes using ERIC-PCR. Genotypes A (n=37; 19%) and B (n=47; 24%) were the most common. Genotype B was the inoculant strain *S. meliloti* RRI128 and DNA sequencing identified Genotype A as *Rhizobium sp*. Plants which had not received the commercial inoculant were also successfully nodulated. Genotype A was most common isolate in the nodules from these plants (n=14; 28%). In 2014, the 180 isolates collected produced 35 unique genotypes. Genotype B was the most common (n=63; 35%). An isolate not recovered in 2011, genotype 1M, was the second most common (n=14; 8%). Genotype 1M was also the most common isolate in the nodules of the uninoculated plants (n=11; 18%). Genotype A was not found. This paper reports on the survival of the commercial inoculant over time and changes in the naturalised rhizobia occupying the nodules of inoculated and uninoculated plants. Greater understanding of factors that influence nodule occupancy should aid selection of persistent strains.

Key words

Alfalfa, ALOSCA®, bare seed, coated seed, peat seed

Introduction

Nitrogen fixation occurs when legumes, such as lucerne, are nodulated by effective strains of rhizobia. In New Zealand this is ensured by applying commercially available inoculants to the seed. The use of commercial inoculant can increase dry matter (DM). Thus, historically there has been little debate on the need for lucerne inoculants on most of agricultural soils worldwide.

Lucerne has been grown in New Zealand pastures for over 80 years. The widespread practice of commercial inoculation means that, paddocks that were historically sown in lucerne may have been inoculated with commercial preparations of the lucerne specific rhizobia *Sinorhizobium meliloti.* Recent studies have demonstrated successful establishment of lucerne crops in New Zealand without inoculation (Wigley 2011; Khumalo 2012). However, no differences in DM production was found between inoculated and uninoculated lucerne. Effective nodules containing *Rhizobium* sp. were formed on the roots of uninoculated plants (Khumalo 2012; Wigley 2011). This work suggests soils into which lucerne is sown frequently contain adequate levels of effective rhizobia capable of nodulating lucerne. Jensen (1941) also reported that rhizobia are able to survive in the soil for 40 years providing temperature and pH are optimal. However, this has yet to be extensively studied. This paper reports on the survival of the commercial inoculant over time and investigates the change in naturalised rhizobia occupying the nodules of inoculated and uninoculated plants.

Materials and Methods

Experimental site

The experiment was located at the Lincoln University Field Research Centre (43°38□S and 172°28□E) on a Wakanui silt loam (*Udic Ustochrept*, USDA Soil Taxonomy) soil with a pH (H_20) of 6.0. The site had previously been grown Lucerne continuously from 2004 – 2007. Prior to the sowing of this experiment the site was in brassicas followed by short rotation annual ryegrass. No fertilizer was applied during the experiment

and plots were grazed as required. The experiment was a randomised complete block design. Plants were excavated from plots sown on the 4th November 2010. Three inoculation treatments (peat, coated and ALOSCA®) plus the bare seed control were the subplots.

Inoculation and sowing

'Stamina 5' lucerne was used for all treatments at a standard bare seed rate of 10.5 kg/ha which equated to 16 kg/ha of coated seed. All inoculant was freshly delivered and applied to reflect standard commercial practice. Peat slurry was prepared as recommended by the manufacturer. The peat inoculant was mixed with water. Immediately prior to sowing, the seed was then coated in the slurry. At sowing, ALOSCA® granules were mixed in the drill with bare seed at the recommended rate of 10.5 kg/ha. The commercially sourced coated seed reportedly contained the inoculant, a contact fungicide against *Pythium* spp., molybdenum and lime. It was stated that all inoculant treatments (peat, coated and ALOSCA®) contained *S. meliloti* strain RRI128. 14 row plots of 4.2 x 7 m with 0.5 m gaps between plots were sown with an Øyjoord cone seeder. The drill hoppers were pressure cleaned with air after each seed treatment and sown in the order of bare seed followed by ALOSCA® mix, coated seed and peat slurry mix.

Nodule collection

In January 2011, two months after sowing, 20 plants were randomly selected from duplicate plots for each of the four inoculation treatments. This was repeated three years after sowing (January 2014) for each inoculation treatment except ALOSCA®, except this time only 6-7 plants were randomly selected as the root systems were substantially bigger and more nodules were present per plant. The number of plants selected was determined by the number of nodules on each tap root. Plants from the edges of the plots were avoided. From each plant, 1 – 10 pink nodules were selected either directly from or within 10 – 20 mm of the main tap root, and were preferentially selected from the upper 10 cm of the root system. In 2011, the number of nodules per plant was often fewer than five whereas in 2014 it was often more than five. Nodules were taken from the peripheral root or lower down the root when no nodules were present on or close to the tap root. A maximum of 10 nodules per plant were collected and at least 50 nodules per inoculation treatment were plated.

Rhizobia were recovered from the nodules and DNA extraction and ERIC PCR of bacterial DNA was carried out as described in Wigley et al. (2015).

Amplification of 16S ribosomal DNA for isolate identification

The 16S rRNA gene of the most common genotypes at each site were amplified for DNA sequencing using primers F27 (5'-AGAGTTTGATC(A/C)TGGCTCAG-3') and R1494 (5' CTACGG(T/C)TACCT TGTTACGAC-3') (Weisburg *et al.* 1991) The PCR products were sequenced at the Lincoln University Sequencing Facility. The sequences obtained were viewed using Chromas Lite 2.1 (Technelysium Pty Ltd, Australia) and manually trimmed using DNAMAN 4.0 (Lynnon Biosoft, Canada) to remove ambiguous sequence. The sequences were then compared with those of known origin on the nucleotide database GenBank (www.ncbi.nlm.nih.gov/genbank/) using the Basic Local Alignment Search Tool (BLAST) (Altschul *et al.* 1990).

Assessment of symbiotic potential

Seeds were surface sterilised by soaking them in 15% commercial bleach (0.25 g/L sodium hypochlorite; 10 min) and rinsed with sterile water. Seeds were then planted in 40 mL of vermiculite and McKnights nutrient solution. Plants were grown in a growth chamber with a 16 h photoperiod at a constant 22°C. 7 days after sowing, seedlings were inoculated by adding 51 mL of one of the selected strains (approximately 1 x 10^6 cfu) in 0.85% saline onto the plant. Uninoculated plants were supplied with saline only and used as controls. There were 10 replicate pottles per treatment. After 49 days dry matter production was be measured and effective nodules were counted.

Statistical analysis

Variables were analysed using Pearson's Chi-square test of independence at $\alpha = 0.05$ to determine any differences between the frequencies of each genotype found in each treatment. The symbiotic potential experiment was analysed using Genstat 16th edition (VSN International). A one way ANOVA was carried

out and Fisher's protected least significant difference (LSD) test was used to separate means for each factor when ANOVA gave a P value < 0.05.

Results and Discussion

In 2011, 194 strains of bacteria were recovered from the nodules of field grown plants, approximately 50 nodules from each treatment. The 194 isolates produced 17 unique genotypes using ERIC-PCR. Genotypes A (n=37; 19%) and B (n=47; 24%) were the most common. Genotypes F (n=23; 11%), G (n=20; 10%) and C (n=14; 7%) were also commonly found. In 2014, 180 strains of bacteria were recovered from the nodules of field grown plants. Of these 61, 59 and 60 were from the bare, lime and peat treated seed, respectively. The 180 isolates produced 35 unique genotypes using ERIC-PCR. Genotypes B (n=63; 35%) and 1M (n=14; 8%) were the most common. Genotype C (n=12; 7%) was also commonly found. All other genotypes occurred in < 10 nodules in total across all treatments. Genotypes A, F and G were not found in any of the nodules in 2014. This work demonstrated that in 2011 and 2014 lucerne nodules were occupied by a wide range of genotypically distinct bacteria even when inoculated with commercial preparations of *S. meliloti* RRI128 and the dominant genotypes changed over time. Jensen (1941) reported that rhizobia are able to survive in the soil for 40 years providing temperature and pH are optimal. It is likely that rhizobia was present in the soil and able to nodulate lucerne as the current experimental site had previously been sown in lucerne. It has also been found that worldwide, plants such as lucerne are nodulated by many strains and species of rhizobia (Burton 1972). However, some of these may be less effective at nitrogen fixation than the commercial inoculants which have been chosen for their ability to fix atmospheric nitrogen at high rates.

Wigley et al. (2015) showed that genotype B is identical to that of the commercial strain RRI128 obtained from the Australian Inoculant Research Group (AIRG). DNA sequencing of one strain from each inoculant produced 850 bp of sequence that had 100% coverage and was identical to strains of *S. meliloti*.

Seed treatment affected (P<0.001) the population of strains recovered (Table 1). Most of this variation was attributable to differences in genotypes A and B between inoculation treatments. In 2011, Genotype B was dominant and recovered from 40% of the nodules plants grown from coated seed (n=20). The lime, molybdenum and fungicide added to the seed coat may have produced favourable conditions for survival of the rhizobia and thus successful nodulation (Lowther and Kerr 2011). In 2014, genotype B was also most common in the nodules from peat and coated seed plants at 64% (n=34) and 48% (n=29). Genotype B occupancy of nodules had increased in both the peat (22%; n=11 vs. 64%; n=34) and coated (40%; n=20 vs. 48%; n=29) seed treatments from 2011 to 2014. In this study only 16% of nodules from plants inoculated with ALOSCA® contained *S. meliloti* strain RRI128 in 2011. Due to the low numbers of the commercial inoculant and genotype A in the nodules of the ALOSCA® plants this treatment was not sampled again in 2014.

Table 1. Frequency/count of the five most common genotypes observed in isolates recovered from the nodules of lucerne plants treated with ALOSCA®, lime coat, peat inoculant, or left as a bare seed control in soils from Lincoln University in 2011.

		Treatment[1]			
		Bare Seed	ALOSCA®	Coated Seed	Peat Seed
2011					
Genotype	**Species**				
A	*Rhizobium sp.*	14	8	0	15
B	*S. meliloti*	8	8	20	11
C	*Rhizobium sp.*	4	7	3	0
F	*Variovorax sp.*	5	7	3	8
G	*Rhizobium sp.*	6	7	7	0
2014					
B	*S. meliloti*	0		29	34
1M	*S. meliloti*	11		3	0
C	*Rhizobium sp.*	9		0	3

[1] Significant at P ≤ 0.001 using Pearson Chi – square test.

Naturalised rhizobia were found in the nodules of plants grown from uninoculated seed (bare seed control). *Rhizobium* sp. (genotype A) was the most common and found in 28% of nodules from plants grown from bare seed at Lincoln University in 2011. Burton (1972) stated that inoculation is essential for lucerne establishment and growth worldwide. In contrast, the results of this study suggested that an inoculant treatment is not always necessary for nodulation. In 2014, a new genotype, 1M was the most common isolated from bare seed plants with 19% (n=11) of nodules containing this genotype. Genotype A was not found. The driver for the change in dominant genotype from genotype A to genotype 1M is unknown but it could be due to the change in land use. Prior to sowing and the first sampling in 2011 the site had been in brassicas in 2008 followed by short – rotation ryegrass from 2009 – 2010. At the time of the second sampling the lucerne had been established at the site for 3 years. This is likely to have influenced the naturalised rhizobia population but more research is required to confirm this.

DNA sequencing of the 16S rRNA gene of the most common genotypes (A, 1M and B) identified them as *Rhizobium* sp. (genotype A) and *S. meliloti* (genotype 1M and B). Genotype C and G were also identified as *Rhizobium* sp. and genotype F was identified as *Variovorax* sp.

Symbiotic potential of the naturalised strains was measured. Shoot dry weight of genotype 1M was not different from shoot dry weight of the commercial strain for lucerne with an average shoot dry weight of 0.0321 g/plant and 0.0413 g/plant. These two strains produced more ($P < 0.001$) shoot dry matter then genotype A (0.0112 g/plant) and the minimal N control (0.0057 g/plant). Plants inoculated with genotype A and genotype 1M all had effective nodules.

Conclusion

The commercial inoculant was dominant in the nodules of lucerne plants grown from peat and coated seed three years after sowing. Plants from all seed treatments, including uninoculated plants were nodulated by naturalised strains of rhizobia. The dominant strain in the nodules of the bare seed plants changed over time from genotype A to genotype 1M. This is possibly due to a change in land use. Genotype 1M produced more dry matter than genotype A and both genotypes formed functional nodules. The effectiveness of these dominant naturalised strains to fix N requires further research.

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Soil carbon storage in the root zone of a perennial grass pasture

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Abstract
Carbon sequestration in soils is an issue of international significance, as soils represent a large carbon pool and can be a major sink for atmospheric carbon dioxide. In southern Australia, soil carbon under agricultural land uses has received attention, particularly in relation to the potential for perennial plants to sequester carbon. Although considerable attention has been applied to carbon sequestration associated with reforestation, there has been less work associated with perennial pastures. It can be argued that farmers are more likely to change pasture than undertake reforestation, thus if carbon mitigation via the land sector is to occur over large areas, the dynamics of carbon under perennial pastures needs assessment. Standard soil testing for carbon stocks extends to a depth of 0.3 m whereas perennial pastures have the potential to grow roots much deeper than this, and potentially can have impacts on soil carbon storage to the full depth of the root zone. In this research we measured soil carbon to a depth of 4.0 m under a replicated trial on a deep sandy soil including plots of Gatton panic (*Megathyrsus maximus*) and plots of a barley/lupin rotation, five years after commencement of the trial. Soil water measurements suggested a maximum rooting depth for the pasture of 3.5 m, and 1.5 m for the annual crops. Despite differences in root depth, there were no significant differences in soil carbon between the two land uses. However, total soil carbon storage was considerably higher (44 t C/ha) when measured to a depth of 4 m compared with the standard 0.3 m depth (23 t C/ha).

Key words
Sub-tropical pasture, Evercrop

Introduction

Increasing atmospheric carbon dioxide concentrations have generated interest in the global carbon cycle, particularly with regard to major storage pools for carbon. Soil carbon is one such major pool, and can sometimes be manipulated by agricultural management (Lal, 2004; Sanderman et al., 2011; Hoyle et al., 2013). In particular, the inclusion of perennial vegetation into farming systems has been identified as a potential pathway for increasing soil carbon (Sanderman et al., 2011).

In Western Australia, adoption of perennial sub-tropical grass pastures is increasing, largely in an effort to reduce wind erosion on soils of marginal cropping potential. The perennial pastures provide year-round ground cover, and growth in response to summer rainfall, which help to reduce the erosion risk. Wind erosion in itself can be a significant source of carbon loss from soil (Harper et al., 2010). Previous research has demonstrated that perennial pastures generally produce deeper root systems than annual plants, (e.g. Ward et al., 2001), and therefore, perennial pastures may be associated with increased soil carbon sequestration (Sanderman et al., 2011). However, in order to determine impacts of perennial pastures on soil carbon, sampling to a depth greater than the Kyoto standard of 0.3 m might be necessary (Harper and Tibbett, 2013).

Sanderman et al. (2013) measured soil carbon under several tropical grasses (including Rhodes grass, Gatton panic and Kikuyu) and showed that Kikuyu was occasionally associated with increased soil carbon (relative to adjacent fields of annual crops and pastures), but Rhodes grass and Gatton panic had no impact on total soil carbon. Similarly, Lawes and Robertson (2012) used paired fields and again showed that Rhodes grass and Gatton panic did not increase soil carbon. However, Sanderman et al. (2013) only measured to a soil depth of 0.3 m (following the Kyoto protocol), and Lawes and Robertson (2012) only measured to 0.9 m. As noted by Ward et al. (2014), Gatton panic and Rhodes grass roots can reach depths of more than 3 m, and so these previous reports did not sample the full rooting depth. In this research we assess carbon in soils to a depth of 4.0 m, encompassing the entire root system of the perennial grass pasture. Measurements are compared with soil carbon to the same depth under a conventional cropping rotation, in a replicated field trial.

Materials and Methods

Site details

A site was chosen on a deep sandy soil at 30° 46' 58"S, 115° 51' 43"E, near Moora, 150 km north of Perth, WA. The surface soil (0.0-0.1 m) had a pH of 5.4. Average rainfall at the site (SILO gridded data set; https://www.longpaddock.qld.gov.au/silo/) is 498 mm, of which 406 mm falls in the May to October period.

Plots were established in a randomised block design with 3 replicates. Treatments included crop plots, perennial tropical grass pasture plots, and combined crop and pasture plots in a system known as pasture-cropping (Lawes et al., 2014). Specifically, plots included: Gatton panic (*Megathyrsus maximus*) pasture, low N (PL); Gatton panic pasture cropped, low N (PCL); Gatton panic pasture cropped, high N (PCH); Crop only, low N (CL); and crop only, high N (CH). Low N treatments received 50 kg N/ha, and high N treatments received 80 kg N/ha. Gatton panic pastures were sown in August 2008, and were maintained until the end of the trial in May 2014. Crops were barley (*Hordeum vulgare*) (2009, 2011, 2013) and lupins (*Lupinus angustifolius*) (2010, 2012). Further details are given in Lawes et al. (2014).

Soil sampling

Soil sampling was conducted in April 2014, in two of the replicate blocks. Depths sampled were 0.00-010, 0.10-0.20, 0.20-0.30 by taking vertical soil cores, and 0.45, 0.80, 1.25, 1.75, 2.25, 2.75, 3.25 and 3.75 m by taking horizontal soil cores. Each depth sampled below 0.3 m was assumed to provide data for the depth range from the mid-point between samples, and the 3.75 m sample was assumed to provide data for the depth range 3.5 to 4.0 m. For each depth, four volumetric soil cores of 0.1 m length and 0.03 m radius were extracted. Soils were air-dried, sieved <2mm, and analysed for soil carbon by LECO combustion. A sub-sample was further dried at 105°C so that carbon contents could be calculated on an oven-dry basis. Soil dry bulk density was used to convert carbon percentage to an estimate of carbon mass per hectare. Material retained on the 2 mm sieve was separated into gravel and root fractions, and each was weighed separately. Carbon content of roots was assumed to be 50% of total root dry matter.

Results

Soil carbon storage

In the surface 0.3 m, there were no significant differences ($p = 0.65$) between the treatments in terms of soil carbon storage (Figure 1a). Average carbon storage was 23 t C/ha. Soil carbon storage summed within the full root profile of 4.0 m averaged 44 t C/ha (Figure 1b), and once again, there were no significant differences ($p = 0.75$) between treatments.

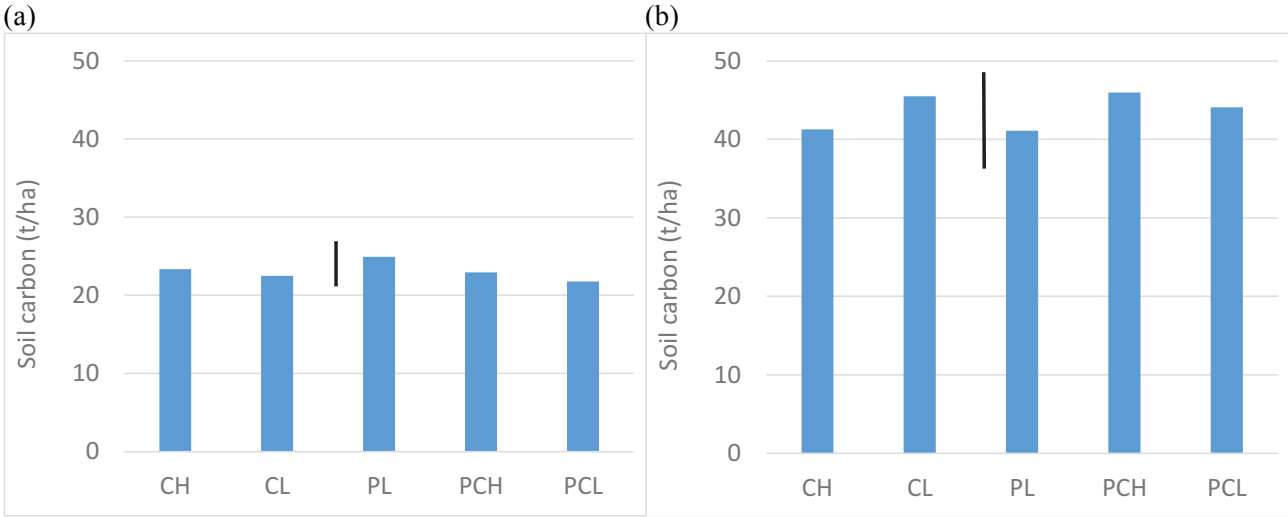

Figure 1. Soil carbon (t/ha) in the top 0.3 m (a) or 4.0 m (b) of soil. Vertical bars represent LSD values. CH and CL indicate crop only, with high or low nitrogen respectively; PCH and PCL indicate pasture cropped treatments with high and low nitrogen respectively; and PL indicates pasture only.

Root distribution and total carbon stock

Root biomass was significantly (p=0.023) greater in the plots containing perennial pasture than in the CH and CL plots (Figure 2a), and virtually all of this difference was due to root material in the top 0.3 m of soil (Figure 2b). However, adding root carbon to the total soil carbon amounts, to give a total carbon sequestration, resulted in no significant differences (p = 0.208) between treatments. Total carbon sequestration (soil plus root) to a depth of 4.0 m averaged 51 t C/ha.

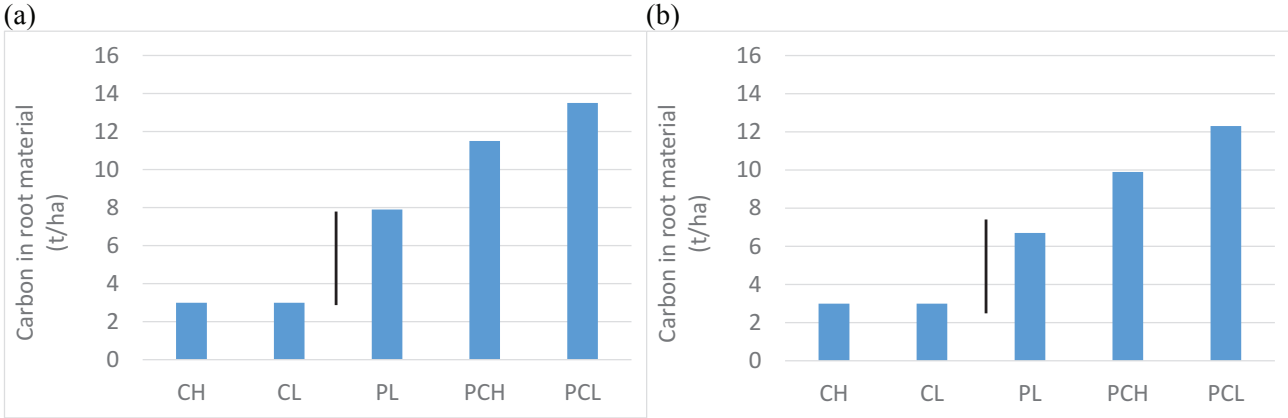

Figure 2. Carbon storage in root material in the top 4.0 m (a) or 0.3 m (b) of soil. Vertical bars represent LSD values. CH and CL indicate crop only, with high or low nitrogen respectively; PCH and PCL indicate pasture cropped treatments with high and low nitrogen respectively; and PL indicates pasture only.

Discussion

Perennial pastures have become more popular over the last few years in the sandplain areas north of Perth. The major driver of this expansion has been the desire to stabilize sandy soils prone to wind erosion, and the perennial growth of the sub-tropical grasses has largely achieved this aim through increased ground cover (Ward et al., 2014). There has also been considerable debate in the farming and scientific communities about the carbon balance of these systems, given the reduced soil disturbance, and increased root growth associated with the perennial pastures. Our results demonstrate that Gatton panic, after five years of pasture growth, did not lead to a measureable increase in soil carbon when compared with an annual cropping rotation, even when measurements extended to the complete depth of the root system. Differences between the treatments may have been observed if pastures had been left for a longer time period (more than 5 years) before sampling. Our results support similar results reported by Sanderman et al. (2013) and Lawes and Robertson (2012), measured over the top 0.3 m or 0.9 m of soil respectively. Interestingly, this is also consistent with results for a study of soil carbon changes following 26 years of reforestation with eucalypts in the same region (Harper et al., 2012), which suggests that soil carbon sequestration may be constrained by the sandy texture of the soils in the region. In our results, sampling to a greater soil depth encompassing the entire root system of the perennial grass pasture did not lead to a different outcome. Therefore, there appears to be little incentive in further deep soil sampling when comparing different land uses of perennial grass pastures and cropping rotations.

Soil carbon, when measured for sequestration calculations, is usually measured in the top 0.3 m of soil. Sanderman et al. (2013) and Roper et al. (2013) found that Kikuyu pasture could result in greater carbon sequestration relative to annual crops or pastures, but that other grasses were less effective. Differences in both experiments were observed mainly in the top 0.1 m of soil, which could be due to decreased wind erosion, as suggested by Harper et al. (2010). In our results, differences in root distribution between the annual and perennial plants were observed, but were largely confined to the top 0.3 m of soil, as also observed by Sanderman et al. (2013). Therefore, even when considering root growth in perennial grass pastures, the top 0.3 m of soil seems to include all the relevant information.

Total carbon stock was substantially higher when measured throughout the top 4.0 m of soil, compared with the top 0.3 m of soil. Harper and Tibbett (2013) also showed that deep soil carbon (up to 38 m deep) can add substantially to the total carbon stock, and should be included in estimates of carbon sequestration. However, our results showed that there was no difference between land uses in terms of the deep soil carbon. While

this carbon is important to include in overall calculations of carbon stock, it does not seem to be a useful indicator of changes in carbon in response to altered land use.

Conclusions

Gatton panic was not associated with increased soil carbon relative to a conventional annual crop rotation, even when measured to the entire depth of the root system. Differences between annual and perennial vegetation were observed in root growth, and there differences were largely confined to the top 0.3 m of soil. Therefore, sampling to the top 0.3 m of soil seems adequate to calculate relative carbon stock in perennial grass pastures.

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Lucerne root dynamics under defoliation regimes

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Abstract
A lucerne pasture requires a recovery period after a defoliation event and that recovery time is more important than the level of defoliation. Repeated defoliation with inadequate recovery leads to loss of production and reduced stand life. Early recommendations were for lucerne to be grazed or cut in fixed rotations with a fixed recovery period throughout the year – typically 5-7 weeks. Current recommendations favour grazing when new lucerne shoots reach 2 cm and grazing for 7-8 days leaving shoots at least 5 cm long. They also often recommend resting lucerne in late summer-autumn until approximately 50% flowering to allow root reserves to be restored prior to winter.

Field experiments at Hamilton and Rutherglen (Victoria) are measuring the effects of 4 defoliation/recovery treatments on root and shoot DM, root C and N reserves and persistence of lucerne. This paper examines the effect of several defoliation regimes, representing those recommended in the past or present, on the maintenance of root yield during the first 5 months of treatment.

To date there are no differences in basal frequency of lucerne between treatments at either site. Root mass has changed between treatments at Hamilton but a consistent pattern has not yet emerged. Root mass has increased at Rutherglen despite poor above ground herbage production. This is surprising considering the generally dry summer-autumn period during the study to date and considering that the Short Rotation treatment has a recovery period considerably shorter than that generally recommended. However, these are early results and this could change as the experiments progress through the changing seasons of the next 12 months.

Keyword
Lucerne, roots, recovery, management, persistence

Introduction
It is well understood that a lucerne pasture requires a recovery period after a defoliation event, and that recovery time is more important than the level of defoliation (McKinney 1974, Pembleton *et al. 2010,* Teixeira *et al.* 2007, Teixeira *et al.* 2008). Repeated defoliation with inadequate recovery leads to loss of production and reduced stand life. New 'grazing tolerant' cultivars are more tolerant of frequent defoliation but this general principle still holds. While recommendations exist around recovery periods after defoliation, evaluation of various recovery regimes in different environments is limited.

Early recommendations were for lucerne to be grazed, or cut, in fixed rotations with a fixed recovery period throughout the year. Early recommendations in New South Wales, and subsequently adopted elsewhere, were for a 35 day recovery period (Clinton 1968). In a large grazing demonstration near Maryborough, Victoria, (Ransom 1992) a 40 day recovery period was used. McKinney (1974) suggested, from his and a range of previously published experiments that the minimum recovery time should be about 7 weeks (49 days).

Popular extension material from Australia and New Zealand now favour grazing when new lucerne shoots reach 2 cm and grazing for 7-8 days leaving shoots at least 5 cm long. They also often recommend resting lucerne in late summer-early-autumn until approximately 50% flowering to allow root reserves to be restored prior to winter (See for example: Anon 1999, Naji 2006, Williams 1996, Anon 2008, Anon 2009).

Lucerne plants mobilise Carbon (C) and Nitrogen (N) reserves from their roots immediately post defoliation and more generally in spring. They accumulate C and N in their roots during summer and early autumn if moisture is available. The management system imposed will affect this pattern however and it is desirable to

understand the compromises that are made and their consequent effects on production, nutritive value of the herbage and persistence of the stand.

This paper examines the effect of four recommended defoliation regimes on the maintenance of root carbon reserves in established lucerne pastures at two contrasting sites in Victoria to test the hypothesis that short defoliation intervals will reduce productivity and stand life. Root yield, to a depth of 40 cm, is used as a relative measure of root carbon reserves. Nie *et al.* 2015 provides descriptions of the sites, soil types and a climate summary.

Methods

Paddocks of lucerne cv Sardi Seven were selected at the DEDJTR research farms near Hamilton (S37.834, E142.086) and Rutherglen (S36.112, E146.518) and the experimental areas fenced off. Each experiment consists of four defoliation/recovery treatments replicated four times in a completely randomised design. Each plot is 10m x 5.5m. The treatments are;

- **LR:** Long recovery cycle of 42 days recovery immediately after defoliation. This represents the historical recommendation of fixed recovery periods, with a long recovery period that would be expected to maintain maximum lucerne productivity and sustainability.
- **SR:** Short recovery cycle of 21 days recovery immediately after defoliation. This represents the historical recommendation of fixed recovery periods, with a short recovery period that is less than most historical recommendations.
- **NS:** Defoliate when new shoots are >2 cm long throughout the year. Plots will be monitored leading up to a defoliation. A defoliation will be triggered if an average of 70% of 10 randomly selected plants per plot have new shoots exceeding 10 cm. This represents a contemporary recommendation for encouragement of new growth.
- **NSF: As for NS** except in early autumn when the lucerne will be allowed to reach late flowering (phenology stage 6-7). Plots will be monitored leading up to a defoliation. A defoliation will be triggered if an average of 70% of 10 randomly selected plants per plot have new shoots exceeding 10 cm. This represents a contemporary recommendation for encouragement of new growth and a prolonged recovery period for the lucerne stand post summer.

Defoliation was achieved by mowing plots to a height of 5 cm. Phenological stage is recorded on a per plot basis prior to each defoliation according to the scale described in Kalu and Fick (1981).

Basal frequency was assessed prior to the first defoliation (20 Nov 2014 at Hamilton; 16 Dec 2014 at Rutherglen). Two 1m x 1m quadrats were established in each plot. Each quadrat had 100 cells and the number of live lucerne plant bases in each cell is counted. The average and between plot standard deviation of lucerne basal frequency were calculated for each of the 2 sites.

After each defoliation (within a couple of days) from late January onwards, in each plot three systematically chosen square soil plugs (0.1 m^2 x 0.4 m deep) were removed and sieved for lucerne roots. The soil, minus the sieved lucerne roots, was then replaced into the holes...Root samples were washed, dried at 60°C and weighed (pre and post drying), before calculating root yield to 40 cm on a dry matter basis.

The root yields, to 40 cm, of different defoliation regimes were compared every three weeks between all defoliation treatments that were sampled within a week of the short rotation regime. At these times the root yield of the three cores in each sampled plot was averaged and these averages were log transformed. The root yields of the defoliation treatments that were sampled were then compared using one way analysis of variance on these log transformed values. In the early stages of the experiment, when there was not yet differentiation between some defoliation treatments, the non-differentiated treatments were considered as a single treatment in the analysis of variance. The experimental unit of all analyses was an experimental plot.

Results

At the start of the experiments the basal frequency of lucerne was 58% (s.d. = 11%) for Hamilton and 44% (s.d. = 7%) for Rutherglen.

Results are presented in Figs 1 and 2. Until the end of February the NS and NSF treatments were identical at both Hamilton and Rutherglen and are analysed together. The NSF treatment was not defoliated during

March and April. At Hamilton there were 8 defoliations in the SR treatment, 7 defoliations in the NS treatment and 4 defoliations in the LR treatment. At Rutherglen there were 6 defoliations in the SR treatment, 4 defoliations in the NS treatment and 3 defoliations in the LR treatment.

During the first 4 to 5 month period of the experiments, during late summer 2014/2015 and autumn 2015 root yield to 40 cm was maintained in the 3500 to 5000 kg/ha range at Hamilton, and increased strongly over time from about 600 kg/ha to 1500 kg/ha at Rutherglen (Fig 1 and 2). It appears that, during this time, the defoliation treatments have had minimal effect on root yield to 40 cm.

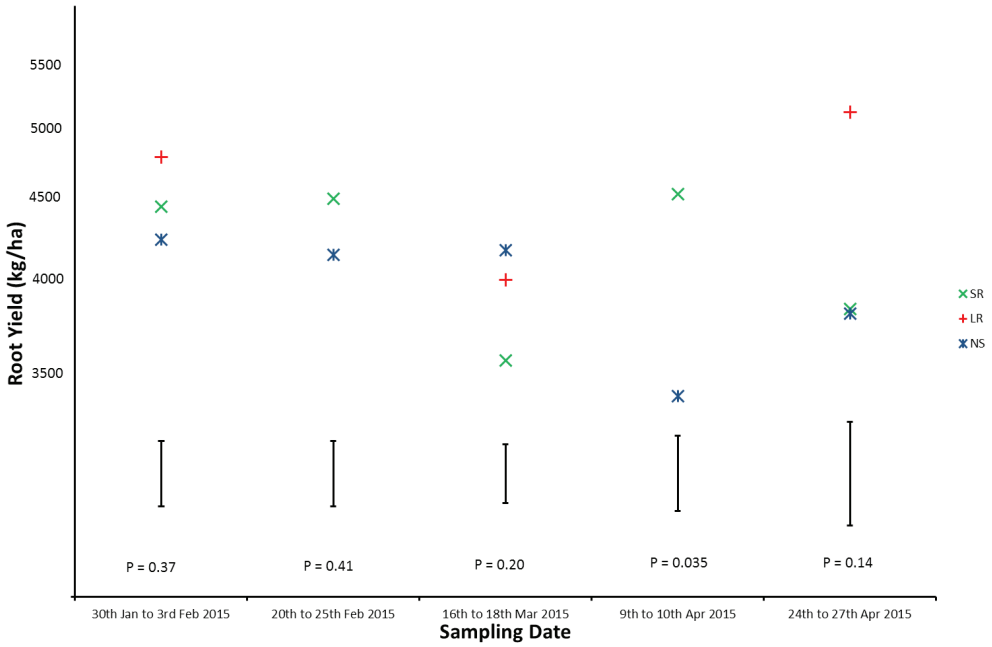

Figure 1. Root yield with short rotation (×), long rotation (+) and new shoot rotation (*), at the Hamilton site on each set of sampling occasions. The root yields (y-axis) are presented on a logarithmic scale and each point represents the geometric mean of all the plots with a specific defoliation regime. The error bars represent the standard error of difference on the logarithmic scale.

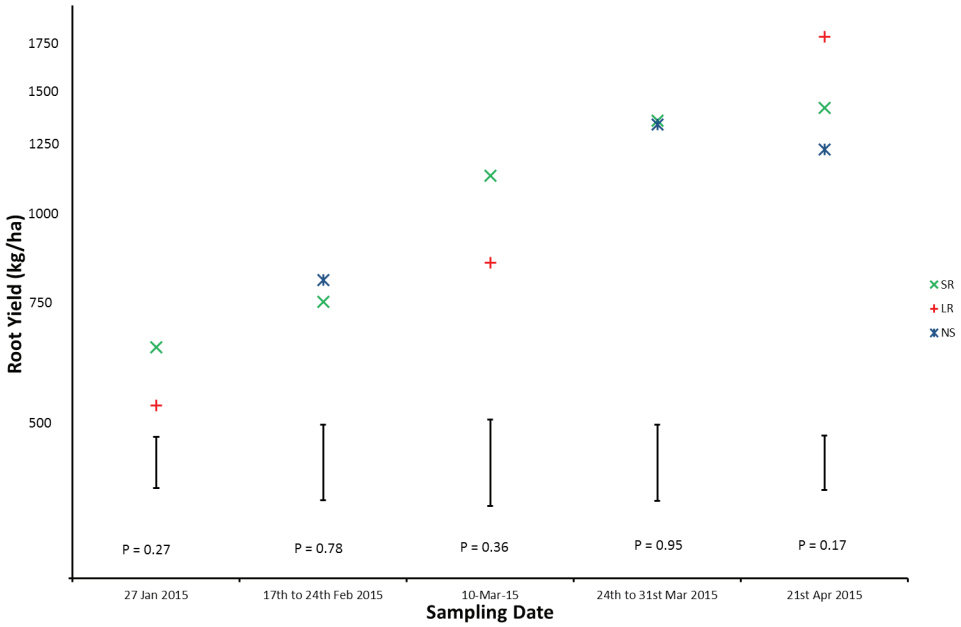

Figure 2. Root yield with short rotation (×), long rotation (+) and new shoot rotation (*), at the Rutherglen site on each set of sampling occasions. The root yields (y-axis) are presented on a logarithmic scale and each point represents the geometric mean of all the plots with a specific defoliation regime. The error bars represent the standard error of difference on the logarithmic scale.

Discussion

Despite both sites having similar initial lucerne basal cover of around 50%, root yield to 40 cm was about 7 to 8 times greater at Hamilton than Rutherglen. This may reflect management history prior to the commencement of this experiment, soil type and weather.

By the end of April, some 4 months into the experiment, there was little evidence of differences between treatments at a site but large differences were evident between sites. Both sites had a dry summer-autumn generally apart from rain in early to mid- January when 40 mm fell at Hamilton over 2 days and 78 mm fell at Rutherglen over 6 days.

At Hamilton there was variation of root mass between treatments but no consistent pattern has yet emerged. At Rutherglen all treatments have seen increasing root mass with each harvest while above ground herbage production has been minimal. Mean total herbage accumulation since the first harvest is 3.4 t DM/ha at Hamilton and 0.7 t DM/ha at Rutherglen. At both Hamilton and Rutherglen the number of defoliations in the new shoot (NS) defoliation regime was intermediate to the number of defoliations in the short rotation (SR) and long rotation (LR) defoliation regimes. However, in this respect, at Hamilton NS was closer to SR than LR whilst at Rutherglen NS was closer to LR than SR.

The different defoliation treatments have had little effect on root carbon reserves to date. This is surprising considering the generally dry summer-autumn period during the study to date, and considering that the SR treatment has a recovery period considerably shorter than that generally recommended (Anon 2008, Anon 2009, Naji 2006, Teixeira *et al.* 2007). However, these are early results and this could change as the experiments progress through the changing seasons of the next 12 months.

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Distribution of lucerne roots in summer-dry environments of southern Australia

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Abstract
In recent years, lucerne (*Medicago sativa*) has been widely sown in productive livestock systems to provide nutritious feed to stock under dry summer conditions in southern Australia. While it is well known that lucerne has deep roots that are important for nutrient and moisture capture, little is known about the distribution of those roots in the soil under the Mediterranean environmental conditions experienced in southern Australia. In summer 2014-15, a field study was conducted to quantify the distribution of lucerne taproots by sampling individual lucerne plants up to 50 cm and all roots in soil cores up to 2 m deep in two contrasting environments, Hamilton and Rutherglen, of Victoria, Australia. The results showed that there was a significant ($P < 0.01$) exponential relationship between the biomass (y) of lucerne taproots and soil depth (x) ($y = 3.22e^{-0.092x}$, $R^2 = 0.95$ and $y = 1.44e^{-0.08x}$, $R^2 = 0.94$ for Hamilton and Rutherglen sites respectively). Based on these equations, it is predicted that the majority of the taproots were present in the top 10 cm of the soil and over 90% in the top 30 cm of soil. There were significant ($P < 0.01$) relationships between the biomass of all roots and soil depth, with the equations being $y = 0.20x^{-1.038}$ ($R^2 = 0.87$) and $y = 0.52x^{-1.171}$ ($R^2 = 0.96$) for Hamilton and Rutherglen, respectively. Based on these equations, it is estimated that over 70% of the total root biomass was in the top 30 cm soil at both sites. These data provide critical information for further research and management on lucerne roots.

Key words
Root biomass, root depth, lucerne sward, individual lucerne plants

Introduction

Lucerne (*Medicago sativa*) is a deep-rooted (> 4 m; Ward et al. 2003) perennial legume that is cultivated as a specialty fodder plant around the world (Humphries 2012). In Australia, lucerne is also extensively used for grazing, providing feed that is often complementary to perennial grass dominated pastures. The capacity to fix atmospheric nitrogen, the high levels of summer production and the adaptation to a broad range of agro-ecological environments have made lucerne the most widely sown perennial legume in southern Australia (Dear *et al*. 2008).

Lucerne roots play a critical role in extracting water and nutrient from the soil and improving the macroporosity of subsoil (McCallum *et al*. 2004). The taproots and the crowns of lucerne also act as a storage organ for endogenous reserves of predominantly carbon (C) and nitrogen (N) in response to changes in management and environmental conditions (Teixeira *et al*. 2007). C and N are generally mobilized from these reserves following defoliation and during early-spring when photosynthesis and N fixation are limited by low leaf area and low temperatures (Avice et al. 1996; Li *et al*. 1996). Re-accumulation of C and N reserves occurs in the later stages of regrowth and in autumn around flowering (Cunningham and Volenec 1998; Khaiti and Lemaire 1992). Ensuring an adequate level of C and N reserves in the taproots and maintaining an appropriate balance between the supply and deposition of C and N are crucial to sustaining the productivity and persistence of lucerne pastures.

An understanding of the root biomass distribution down the soil profile is fundamental to determine the appropriate sampling depth for quantifying the root reserve dynamics. However, there is little information about how lucerne roots, especially taproots, are distributed in the soil. Denton *et al*. (2006) measured the root length and biomass of lucerne at different depths up to 1 m and found that the majority of roots were concentrated in the surface soil (0 – 10 cm). The study was conducted using a pot experiment and did not capture the depth and variation that may be seen in field situations. The objectives of this study were to 1) quantify the relationship between soil depth and the biomass of taproots from individual lucerne plants, and 2) quantify the relationship between soil depth and the biomass of all roots under lucerne stands in two contrasting summer-dry environments of Victoria, Australia.

Methods

An experiment was conducted on two lucerne (cv SARDI 7) paddocks at Hamilton and Rutherglen, Victoria, Australia (Clark *et al*. 2015). At the Hamilton site, the soil was a ferric-sodic eutrophic brown Chromosol (Isbell 2002). The long-term (1965-2015) average maximum and minimum temperature were 18.4°C (12.0°C in July – 25.9°C in February) and 7.1°C (4.2°C in July – 10.9°C in February). The long-term average annual rainfall was 684 mm. The pasture was dominated by lucerne with a mean basal frequency of 57.5% measured in November 2014. At the Rutherglen site, the soil was a sub order brown Chromosol. The long-term (1912-2014) average maximum and minimum temperature were 21.7°C (12.4°C in July – 31.4°C in January) and 7.3°C (2.0°C in July – 13.9°C in February). The long-term average annual rainfall was 587 mm. The pasture was dominated by lucerne with a mean basal frequency of 41.1% in December 2014.

Taproot biomass distribution was measured by collecting 7 individual plants to a depth of 50 cm at both sites in summer 2015. The plants were washed, trimmed to remove any green material from the crown and then placed on a bench in their natural shape between two rulers. The roots (including crown) were cut into 3-cm segments (0 – 3, 3 – 6, …) and oven dried at 100°C for 24 hours. The distribution of all roots from lucerne stands was measured by randomly collecting 12 cores up to 2 m at both sites in November 2014. The diameter of the soil cores was 4.2 cm and 3.8 cm for Hamilton and Rutherglen, respectively. The cores were cut to 0 – 10, 10 – 30, 30 – 50, 50 – 70, 70 – 90, 90 – 110, 110 – 130, 130 – 150, 150 – 170 and 170 – 200 cm in the field. Each of the core segments was soaked in 5% sodium hexametaphosphate for 24 hours before being washed using a root washing device (Ridley and Windsor 1992) to collect all roots (tap, lateral and fibrous roots). The roots were then dried at 60°C for 72 hours. Nonlinear regression models were used to quantify the relationships between soil depth and the biomass of taproots from individual plants and all roots under the lucerne swards.

Results and discussion

The relationship between soil depth (x) and the biomass (y) of taproots followed an exponential curve ($P < 0.01$) at both Hamilton and Rutherglen (Figure 1). The equation of the curves was $y = 3.22e^{-0.092x}$ ($R^2 = 0.95$) for Hamilton and $y = 1.44e^{-0.08x}$ ($R^2 = 0.94$) for Rutherglen. This implies that the taproot biomass declined dramatically in the top soil (0 – 10 cm) and upper part (10 – 30 cm) of the subsoil regardless of the site conditions. The reduction in taproot biomass was more gradual from 30 cm onwards. Based on these equations and the estimate of total taproot biomass in the top 2 m soil, the cumulative biomass of taproots along the soil profile and its proportion to total soil biomass were calculated. These results revealed that the majority (58 – 63%) of lucerne taproots from individual plants was in the top 0 – 10 cm soil and over 90% in the top 0 – 30 cm soil (Table 1). This result supports the finding of Denton *et al*. (2006). The taproot biomass of individual plants from Hamilton (mean = 11.6 g/plant) was higher than that from Rutherglen (mean = 5.6 g/plant), reflecting the differences in temperature and rainfall, and possibly soil texture, soil fertility and age of the swards, between the two sites.

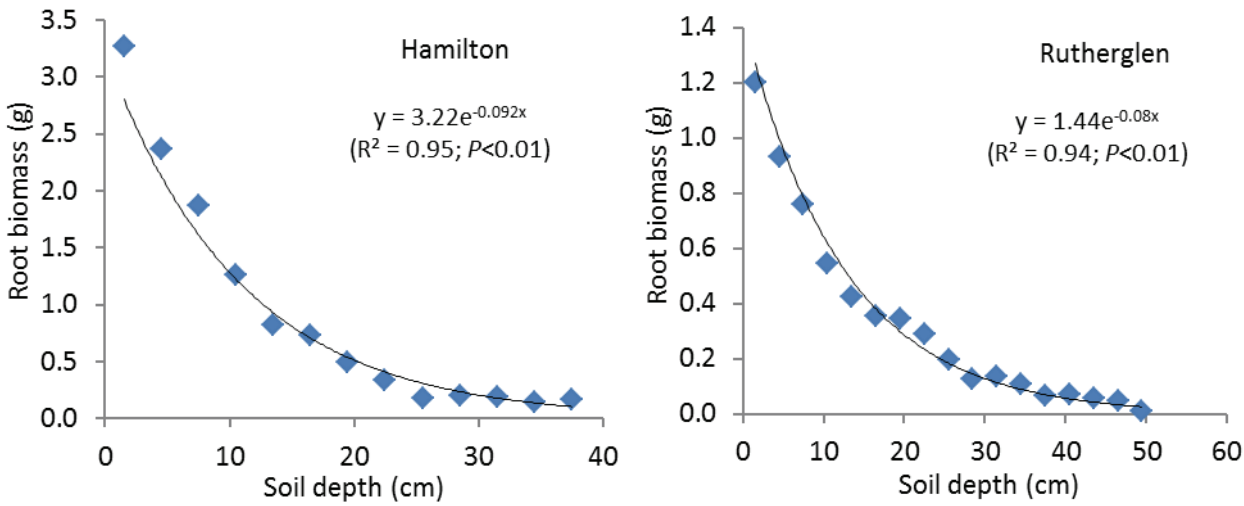

Figure 1. Relationships between root biomass (g in every 3 cm depth) of individual lucerne plants and soil depth at Hamilton and Rutherglen.

There were significant (P<0.01) relationships between the soil depth and the biomass of all roots with the equation being $y = 0.20x^{-1.038}$ ($R^2 = 0.87$) for Hamilton and $y = 0.52x^{-1.171}$ ($R^2 = 0.96$) for Rutherglen (Figure 2). With these relationships, the sharp decline in all root biomass occurred from 0 to 50 cm soil depth, which was deeper than the responses of taproots to soil depth at both sites. This was probably due to the lateral and fibrous roots that may have grown vigorously in up to 50 cm of the soil. Based on the equations and the estimated total biomass of all roots in the top 2 m soil, the cumulative biomass of all roots along the soil profile and its proportion to total soil biomass were calculated (Table 1). Over 50% of the roots were in the top 0 – 10 cm soil, but only over 70% in the 0 – 30 cm soil, which is much lower than the proportion (> 90%) of taproots in this soil depth. The differences in the proportion of the cumulative biomass between taproots and all roots along the soil profile indicate that, while the taproots became fine roots beyond 30 cm depth, there was still a large quantity of lateral and fibrous roots deeper in the soil. These roots may not be able to play a role of storing nutrients for plant regrowth (Teixeira *et al*. 2007), but could function to extract water and nutrients from deep soil, which is critical to lucerne growth (Lamb *et al*. 2000).

Table 1. Cumulative biomass (CM; g) of taproots and all roots and their proportion (%) along the soil profile at Hamilton and Rutherglen based on the equations from Figures 1 (taproots) and 2 (all roots) and the total root biomass in the 2-m soil profile.

Soil depth (cm)	Taproots				All roots			
	Hamilton		Rutherglen		Hamilton		Rutherglen	
	CM	%	CM	%	CM	%	CM	%
10	7.4	63.3	3.5	58.2	0.6	52.6	1.3	62.0
30	10.9	93.7	5.4	90.9	0.8	70.3	1.7	78.0
60	11.6	99.6	5.9	99.2	0.9	81.4	1.9	86.8
90	11.6	100.0	6.0	99.9	0.9	87.7	2.0	91.6
120	11.6	100.0	6.0	100.0	1.0	92.2	2.0	94.7
150	11.6	100.0	6.0	100.0	1.0	95.6	2.1	97.1
180	11.6	100.0	6.0	100.0	1.1	98.4	2.1	98.9
200	11.6	100.0	6.0	100.0	1.1	100.0	2.1	100.0

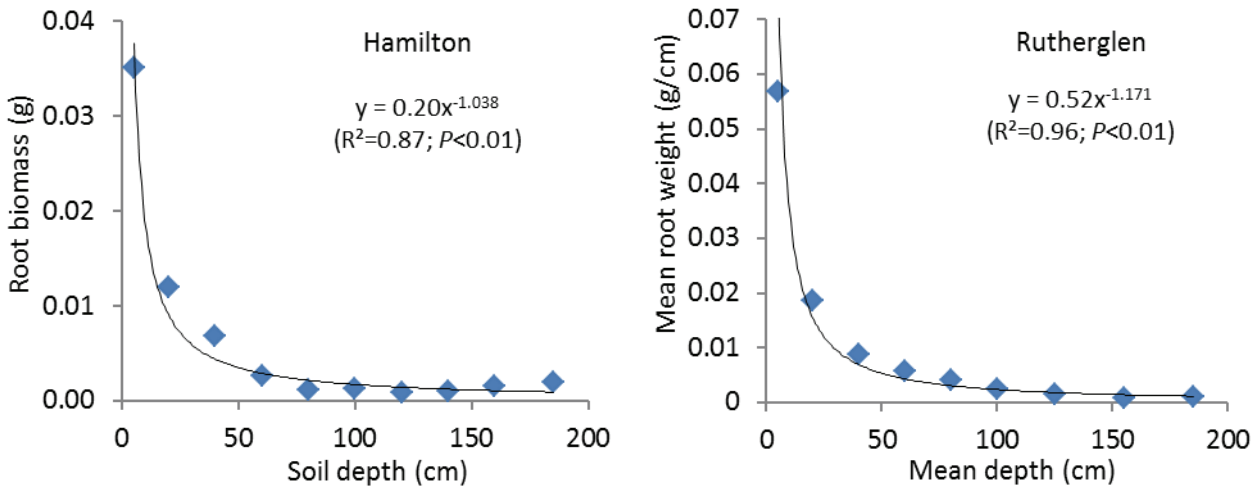

Figure 2. Relationships between the biomass (g in 1 cm depth) of all roots and soil depth at Hamilton and Rutherglen.

Given both the taproot size from individual lucerne plants (Figure 1) and the basal frequency of lucerne in the swards were higher at Hamilton than at Rutherglen, it was expected that the biomass of all roots would be higher at Hamilton as well. Interestingly, the biomass of all roots from the lucerne swards was higher at Rutherglen (1.47 g/core or 0.65 mg/cm^3 soil) than at Hamilton (1.02 g/core or 0.37 mg/cm^3 soil). The cause of this difference is complicated since the biomass of the root systems can be affected by a range of climatic, edaphic and management factors and the responsive level of the plants to these factors (Luo *et al*. 1995; Denton *et al*. 2006). Environmental stress and deficiency of soil nutrients have been reported to increase the root : shoot ratio, the amount of fine roots, the length of root hairs and the production of root material

due to increased allocation of resources to root growth (Barta 1975; Bélanger *et al*. 1992; Powell and Ryle 1978; Gahoonia and Nielsen 2004). Whether these have contributed to the greater biomass of all roots at Rutherglen needs further investigation.

Conclusion

The results clearly demonstrated that, although lucerne is a particularly deep-rooting plant, the majority of the roots in terms of biomass are distributed in the top 30 cm of soil regardless of the differences in site conditions and root types (taproots vs all roots) in the Mediterranean environments of southern Australia. While the dense taproots were concentrated in the shallow top soil (0 – 10 cm) and upper part of subsoil (10 – 30 cm), dense fibrous roots were also distributed in the soil up to a depth of 50 cm. These findings provide important information for lucerne root research and management. Soil nutrient deficiency, bulk density and environmental stress may alter the growth and distribution of lucerne taproots and fibrous roots in these environments, which requires further investigation.

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Nitrogen uptake and nitrogen use efficiency of forage kale crops grown under varying amounts of water and nitrogen fertiliser rates in shallow soils

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Abstract
Grazing of forage kale can cause ground-water pollution through nitrate leaching, particularly in wet conditions. To minimise nitrogen (N) loading, N supply should be matched with crop requirements to achieve an optimum combination of yield and N content for given soil water conditions during crop growth. An experiment was conducted on a stony silt loam soil to investigate dry matter (DM) yield, N uptake and apparent N use efficiency (*a*NUE) under varying water and N inputs. Treatments comprised a factorial combination of two water treatments [rain-fed (control) and full irrigation] and four N rates (0, 75, 150 and 300 kg N/ha), applied three times during the first 13 weeks after sowing. With rain-fed treatments, DM yield increased from 5 t DM/ha for the 0 kg N/ha crops to 11 t DM/ha for the 300 kg N/ha crops. Similarly, DM yield increased from 10 to 25 t DM/ha for the same respective treatments under irrigation. Total N uptake differed with N application rate and increased from 86 kg N/ha for the 0 kg N/ha crops to 350 kg N/ha for the 300 kg N/ha crops but was unaffected by the irrigation treatments. Apparent NUE increased with water application, from 5 kg DM/kg N in the rain-fed treatment to 54 kg DM/kg N when irrigated, but was unaffected by the N application rate. Management practices that increased the *a*NUE achieved the best environmental outcome as productivity was maintained at high levels, herbage N concentrations achieved acceptable levels and residual N in soil decreased.

Key words
Brassica oleracea var. *acephala* L.; apparent nitrogen use efficiency, leaching, N uptake.

Introduction
Forage kale (*Brassica oleracea* var. *acephala* L.) is an important crop for winter feeding, particularly in the dairy production systems of the South Island, New Zealand (Chakwizira *et al*. 2015a, b) and Tasmania, Australia (Pembleton *et al*. 2015). Forage kale crops have large nutrient requirements, particularly for nitrogen (N) (Wilson *et al*. 2006), and these authors have shown that suboptimal N and water supply results in poor yields. Under high fertiliser N inputs yield is enhanced, but excess amounts of N can lead to the accumulation of nitrate-N in the plant (Chakwizira *et al*. 2015b), potentially leading to animal health issues and/ or environmental pollution. The risk of nitrate leaching is high on soils with low water holding capacity (WHC) and if winter grazing occurs during periods of high rainfall. Management of crops to match N supply and crop N demand is a logical approach; however, N application rates will depend on background soil fertility, soil moisture and yield potential (Wilson *et al*. 2006). There are quantitative data on N uptake and partitioning (Wilson & Maley 2006), apparent N use efficiency (aNUE; Chakwizira *et al*. 2015a) and water use efficiency (Chakwizira *et al*. 2014) for deep soils with moderate to high WHC. However, there is little research on the combined effects of water and N on growth of forage kale crops grown on shallow and stony soils in New Zealand, where most of these crops are grown for winter grazing. The objective of this experiment was to determine responses to irrigation and N fertiliser and their interactions on DM yield, N uptake and aNUE of forage kale crops grown in shallow soils.

Materials and Methods
The experiment was conducted at the Lincoln University dry-land research farm, Ashley Dene (43°38’45.5”S 172°20’34.4”E, 30 m a.s.l.). The site was situated on a shallow Balmoral stony silt loam soil (Webb & Bennett 1986), with shallow topsoil (0.2 m in depth) over gravel. The soil has a WHC of about 90 mm/m of depth, recalculated from Sim *et al*. (2012). The site was previously in lucerne (*Medicago sativa* L.) from 2008 to 2011 followed by kale from 2011 to 2013. The climate at Ashley Dene is temperate, with mild to

cool winters and warm summers. Mean annual rainfall is 600 mm, distributed evenly throughout the year (NIWA 2014). Weather data from a temporary weather station at the experimental site and long-term data from the Broadfields meteorological station (NIWA 2014) at Lincoln (~10 km from the site) are shown in

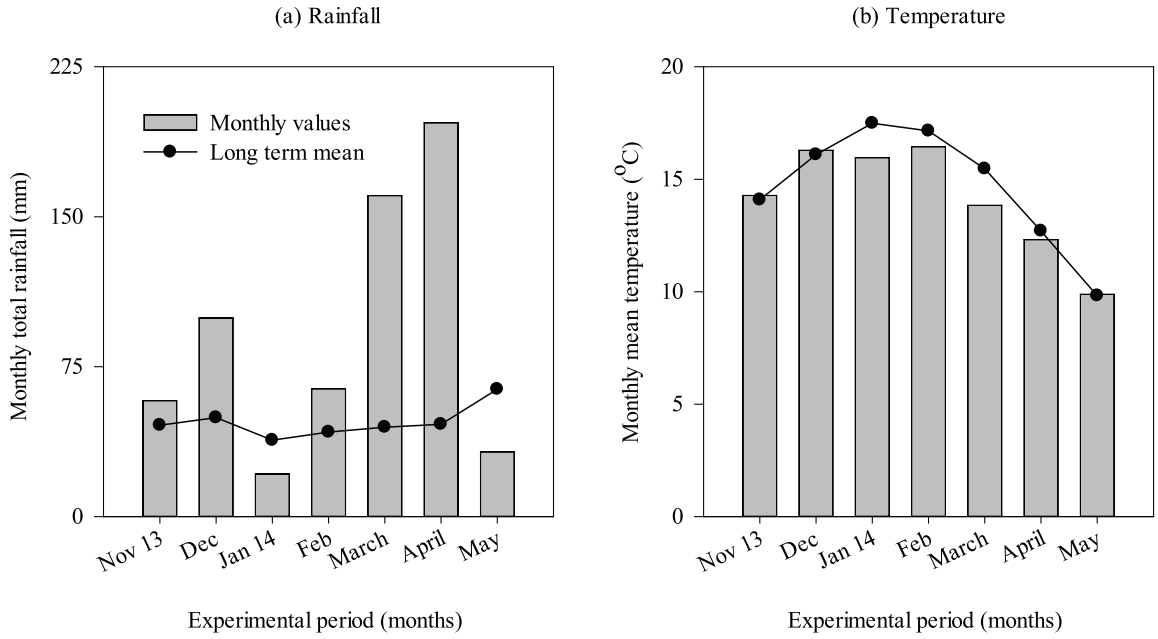

Figure 1: Monthly (a) total rainfall and (b) average temperature at Ashley Dene, Canterbury, New Zealand. Long-term data are from 1970 to 2010 (NIWA 2014).

The experiment was a randomised block design, consisting of eight treatments: a factorial combination of four nitrogen rates (0, 75, 150 and 300 kg N/ha) and two rates of irrigation [rain-fed control and full irrigation replacement of potential evapotranspiration (ET)]. Irrigation was applied twice weekly (maximum = 50 mm/week if no rain) to replace ET. Cultivation involved deep ploughing followed by power harrowing. Soil samples to 0.15 m depth were collected on 30 July 2013 and the average soil test results were: pH 5.8, P 16 mg/kg, K 160 mg/kg, Ca 1000 mg/kg, Mg 45 mg/kg, Na 25 mg/kg, sulphate-S 5 mg/kg soil and available mineral N 78 kg/ha. Basal fertiliser comprising 250 kg/ha triple superphosphate (0-20.5-0-1) and 10 kg/ha borate 46 (15% boron) was broadcast and incorporated into the soil before sowing. Soil mineral N (nitrate and ammonium) tests were taken from individual plots before the application of the N fertiliser treatments and also at the end of the season to a depth of 0.3 m. Nitrogen fertiliser treatments were applied as urea (46% N) on three dates [30, 57 and 91 days after sowing (DAS)] with 20%, 40% and 40% of the total N per treatment (0, 75, 150, and 300 kg N/ha) applied on each date, respectively.

Final dry matter (DM) harvest was performed on 21 May 2014 and involved removing all plants within a 1 m^2 quadrat to approximately 0.1 m height in each plot. The number of plants and total fresh mass per quadrat was determined in the field and a representative five-plant subsample was retained to determine total DM yield. Dry mass was determined after drying at 60˚C to a constant mass. Total N concentration was determined by the Dumas combustion using a LECO CNS-200 analyser (LECO Corporation, St Joseph, MI). Total N uptake was then calculated as the product of crop DM yield and the concentration of N. Apparent NUE was defined as the ratio of additional DM yield to fertiliser N input. This differs from the traditional calculations of NUE as a quotient of total DM and total available N (soil N plus fertiliser N) (Moll et al. 1982).

Data were analysed using analyses of variance (ANOVA) in GenStat v.14 (VSN International, Hemel Hampstead, UK). Significant interactions and main effects were separated using Fisher's protected least significant difference (LSD) tests (α=0.05).

Results and discussion

Final DM yield increased ($P < 0.01$) with both water and N supply from 5.2 t DM/ha for the 0 kg N/ha crops to 11.3 t DM/ha for the crops receiving 300 kg N/ha under the rain-fed treatments (Figure 2), and from 10.1 t DM/ha to 25.8 t DM/ha for the same respective N treatments under full irrigation. These results are consistent with literature (Chakwizira *et al*. 2015a, b; Wilson *et al*. 2006).

The amount of N taken up by the crops was unaffected (P = 0.30) by the irrigation treatments (Table 1) but increased (P< 0.001) with N application from a mean of 88.6 kg N/ha for the no N control treatments to 350 kg N/ha for the 300 kg N/ha treatments. These N responses are consistent with Chakwizira *et al*. (2015a); however, the water responses are inconsistent with previous reports for crops grown under deep soils with high WHC, where water availability had strong effects on N uptake (Chakwizira *et al*. 2013). The lack of response to water could be attributed to the high rainfall during March and April (Figure 1) when growth rates recovered in the rain-fed treatments and any surplus soil N was utilised. In shallow soils, the timing of autumn rain can have important consequences for N loading effects on potential N leaching during winter grazing.

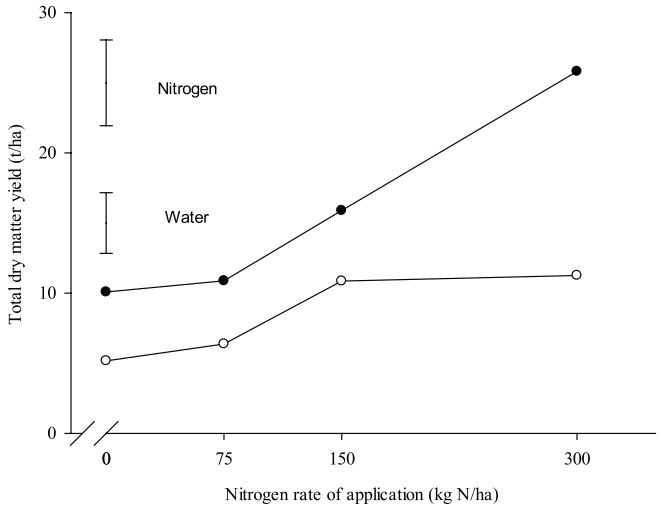

Figure 2: Total dry matter yield of forage kale crops grown with (˜) and without (™) irrigation under different nitrogen rates at Ashley Dene farm, Canterbury, New Zealand in the 2013–14 season.

The aNUE was higher (P<0.001) for the irrigated crops, with a mean value of 54 kg DM/kg N applied compared with 5 kg DM/kg N applied for the rain-fed crops (Table 1). However, aNUE was unaffected (P = 0.88) by N supply, with a mean value of 29 (13-38) kg DM/ kg N applied. This was inconsistent with the results of Chakwizira et al. (2015a) where aNUE was reported to decrease with increasing N supply. The aNUE for the irrigated crops (Table 1) was within the range of 51–112 kg DM/kg N applied (Chakwizira et al. 2015a).The inconsistencies could be attributed to the timing of N application, rainfall distribution, and overall N uptake. For all the treatments, 60% of the fertiliser was applied by 10 December, and this period received about twice the long-term mean rainfall for December (Figure 1). Some of the N fertiliser may have been lost through early leaching. This period was followed by a very dry period in January–February, coincidentally, the period when the remaining 40% of the fertiliser was applied. In the rain-fed crops, N may have been leached at both ends of the season and remained unused during the dry summer period (Jan–Feb), thus compromising DM production. The dry period also coincided with the period of high radiation and therefore high potential growth rate. The high rainfall period, at the end of the season, would have likely allowed the rain-fed crops to take up the N that was resident in soil and hence the similar amounts taken up by the crops under both water treatments. Late-season rain also coincided with decreasing temperatures (Figure 1) and radiation, resulting in lower DM accumulation. Late-season N uptake was higher in the rain-fed crops with comparable final N accumulation in both water treatments.

Table 1.Total nitrogen uptake (kg N/ha) and apparent nitrogen use efficiency (*a*NUE; kg DM/kg N applied) for forage kale crops grown under different rates of nitrogen with and without irrigation, at Ashley Dene, Canterbury, New Zealand in 2013–14 season.

N rate	N uptake		Apparent NUE[a]	
	Irrigated	Rain-fed	Irrigated	Rain-fed
0	109.8	67.4	-	-
75	133.6	93.7	33.8	-7.1
150	189.4	237.4	60.0	16.8
300	374.4	327.4	68.8	3.9
$LSD_{0.05}$				
Water	41		29*	
N rate	58***		35	
Interaction	82		37	

[a]No aNUE for the control plots, as no N was applied.

Conclusions

The DM yield of the rain-fed treatments increased from 5 t DM/ha for the 0 kg N/ha crops to 11 t DM/ha for the 300 kg N/ha treatments. Similarly, DM increased from 10 to 25 t DM/ha for the respective treatments under irrigation. The similar amounts of N uptake between irrigation treatments and the lower *a*NUE for the low yielding rain-fed crops meant that these crops had higher tissue N concentration, and subsequently could lead to higher urinary N deposited into the soil when livestock are fed *in situ* on these crops leading to N leaching during wet winter seasons. Management of N in rain-fed crops is therefore important, and it is therefore recommended to split apply N through the season and following rainfall events. As this experiment was done on a single site and season, the results will need to be confirmed by repeating this study for another season.

Acknowledgements

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The feasibility of fertilising oats and forage sorghum with nitrogen and phosphorus in the Brigalow belt of Queensland: A modelling study

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Abstract
Annual forage crops such as oats and forage sorghum are sources of high-quality feed for mixed grain and beef enterprises in the northern region. However forage productivity declines over time as organic matter and subsequent supply of nutrients decrease with continued cultivation. The use of fertilisers to maintain production from oats and forage sorghum is common practice in higher rainfall and irrigated situations, however fertiliser use in generally drier and more variable environments such as the Brigalow belt is minimal despite declining productivity. We undertook a desktop, modelling assessment of the feasibility of fertilising these forages with nitrogen and phosphorus in the Brigalow belt in southern and central Queensland to better understand the dry matter and feed quality responses necessary to generate positive economic impacts. Results indicated significantly higher dry matter production is possible with fertiliser use, which can lead to higher animal liveweight gain and stocking rates. However under current market conditions the additional costs associated with applying fertiliser outweighed the extra benefits that can be generated. A combination of high dry-matter and animal production responses, lower costs associated with fertiliser application and positive price margins for the livestock grazing the forage are required to make fertiliser application consistently profitable. This modelling study demonstrates land-managers in the northern region need to carefully consider and monitor both the production and economic responses from trial areas before paddock scale applications are implemented.

Key words
Northern region, modelling, oats, forage sorghum, gross margin.

Introduction
Annual forage crops such as oats and forage sorghum are sources of high-quality feed for mixed grain and beef enterprises in the northern region. Oats is the most commonly utilised annual winter forage, producing high quality feed at a time of the year when perennial sub-tropical pasture quality is low. This often enables graziers to finish stock six months earlier compared to if oats wasn't sown. Forage sorghum is popular during summer due high forage production that can support high numbers of stock. However forage sorghum grows at a time when sub-tropical perennial pastures are actively growing and are high quality, so one claimed benefit is to spell or rest large areas of grass pastures over the wet season. Other reasons for growing annual forages include: filling feed gaps; flexibility to match feed supply to seasonal conditions; opportunity to conserve excess fodder through hay or silage; consistent growth of stock throughout their lives to target premium markets (e.g. Meat Standards Australia grading).

Adequate soil nutrition is required to attain high amounts of quality forage for high animal performance (live-weight gain and stocking rate). In high fertility soils or recently cleared country, the inherent fertility and mineralisation from soil organic matter can generally supply enough of the main nutrients (nitrogen, phosphorus, sulphur and potassium) to sustain high forage yields and high feed quality. As cropping continues, without inputs and with cultivation soil organic matter declines and so does the supply of these nutrients to the point when fertilisers are needed to overcome nutrient deficiencies. Production and economic outcomes of fertilising these forage crops can be highly variable. Fertilisers add expense and generally high dry matter and live weight gain responses are required to overcome this extra cost. Despite declining productivity there is minimal fertiliser use in the generally drier and more variable environments such as the Brigalow belt. However limited studies have been carried out to determine the outcomes generated when these forages are fertilised with nitrogen and phosphorus.

Methods

A desktop, modelling study was undertaken to determine the feasibility of fertilising oats and forage sorghum in the Brigalow belt areas of southern and central Queensland. Modelled dry-matter (DM) production data from APSIM and information and data from past published research trials were analysed (Bell et al. 2012; Bowen et al. 2010; Chataway et al. 2011a; Chataway et al. 2011b), and regional experts consulted to ensure adequate coverage of readily available data. Expected biophysical production scenarios were then constructed in a spreadsheet to cover discrete soil fertility and rainfall scenarios possible from the geographic region.

Two separate forages (oats and forage sorghum) were modelled with three base levels of starting production with a range of levels of response to two different fertilisers. Forage sorghum had starting base production levels of either 5000, 10000 or 15000 kg DM per Ha per annum. These starting levels are taken to represent starting levels of inherent soil fertility not different starting levels of plant available water. Similarly, oats had starting base production levels of either 2000, 4000 or 6000 kg DM per Ha per annum.

The starting levels of forage production were taken to represent the likely average production of paddocks that were: (i) restricted by soil nutrient supply; (ii) slightly restricted by soil nutrient supply; or (iii) no soil nutrient restriction. All are taken to have the same underlying level of soil water holding capacity. Paddocks in such condition are considered the most likely to show an economic response to the application nitrogen and phosphorus fertiliser.

The response to nitrogen fertiliser was tested by treating each starting level of each forage crop with 50 kg N or 100 kg N and predicting an average extra response of 0.05kg/hd/d liveweight gain at 50kg/ha fertiliser input, 0.1kg/hd/d liveweight gain at 100kg/ha fertiliser input for forage sorghum, and 0.1kg/hd/d liveweight gain at 50kg/ha fertiliser input and 0.2kg/hd/d liveweight gain at 100kg/ha fertiliser input for oats.
To test the response to phosphorus, the middle level of production (10000 kg DM /ha forage sorghum and 4000 kg DM /ha oats) was treated with either 5kg P or 10 kg P per hectare with a range of responses estimated.

The economic impact of applied fertiliser on beef production was assessed using paddock level enterprise budgets and discounted cash flow techniques from costs and prices relevant to the market conditions in southern and central Queensland in 2014. This method was assessed as the most appropriate way to filter the production responses and identify the level of response needed to improve the relative profitability of the different levels of forage systems. The impact of the predicted responses is largely limited to how they compare in a relative sense to the base treatment. The paddock level enterprise modelled was a steer turnover/bullock production enterprise that purchased store steers and sold finished bullocks direct to the meatworks. The boundaries of the enterprise were the physical paddock boundaries. The only expenses incurred by the paddock enterprise are those that vary with the number of cattle run in the paddock such as husbandry and selling costs. An allowance was made for the amount of additional effort and cost required to apply the fertiliser. The enterprise budgets were compiled in the form of paddock gross margins and were be used to identify the profitability of differing levels of fertiliser response within paddocks.

Results

Forage sorghum – Phosphorus fertiliser

The application of phosphorus fertiliser on forage sorghum makes the financial result worse in all cases ie negative gross margin for all scenarios (data not shown). At the levels of response, prices and costs chosen, there appears to be no realistic scenario for the application of phosphorus fertiliser to forage sorghum that appears capable of significantly improving the returns of the producer.

Forage sorghum – Nitrogen fertiliser

The application of nitrogen fertiliser on forage sorghum made the financial result worse in all cases. Except for the base scenario of 15000kg DM/ha without fertiliser, gross margins were negative (Figure 1). Increasing the production of beef through the addition of fertiliser simply increased the losses made. The relatively poor economic performance of the forage sorghum 'with' and 'without' fertiliser is largely a result of the high costs of producing the additional forage, the poor conversion rate of the additional forage to additional beef and the low price premium (on average) between the buying and selling price of the steers.

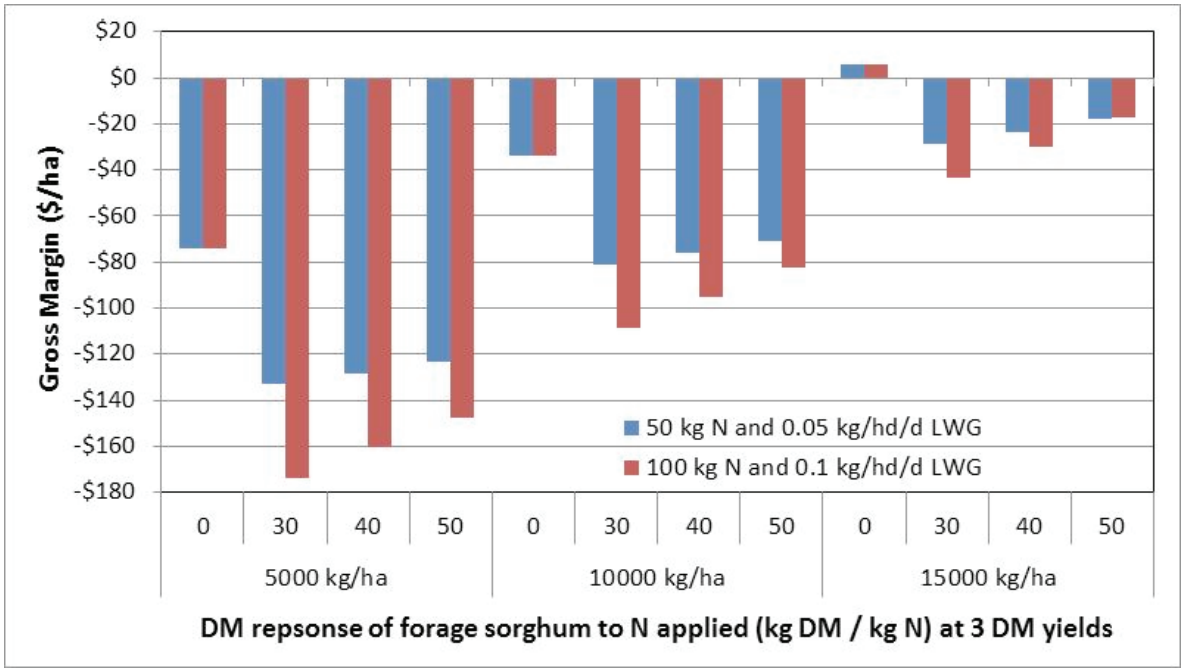

Figure 1. Gross margin for N fertiliser treatments and responses for forage sorghum

Oats – Phosphorus fertiliser

Most production scenarios produced negative gross margins. A plant response of 40 kg DM/kg P applied with an extra liveweight gain of 0.2 kg/hd/d is needed before a barely positive gross margin is achieved (Figure 2). The highest gross margin of around $50/ha was achieved when a plant response of 160 kg DM/kg P applied and 0.2 kg/hd/d extra liveweight gain. It appears that oats crops which have a moderate level of production may show a profitable response to applications of phosphorus if a very high stocking rate response per kilogram of fertiliser applied plus a high weight gain per head response can be achieved. However low soil P levels together with high soil moisture or irrigation are needed before this occurs.

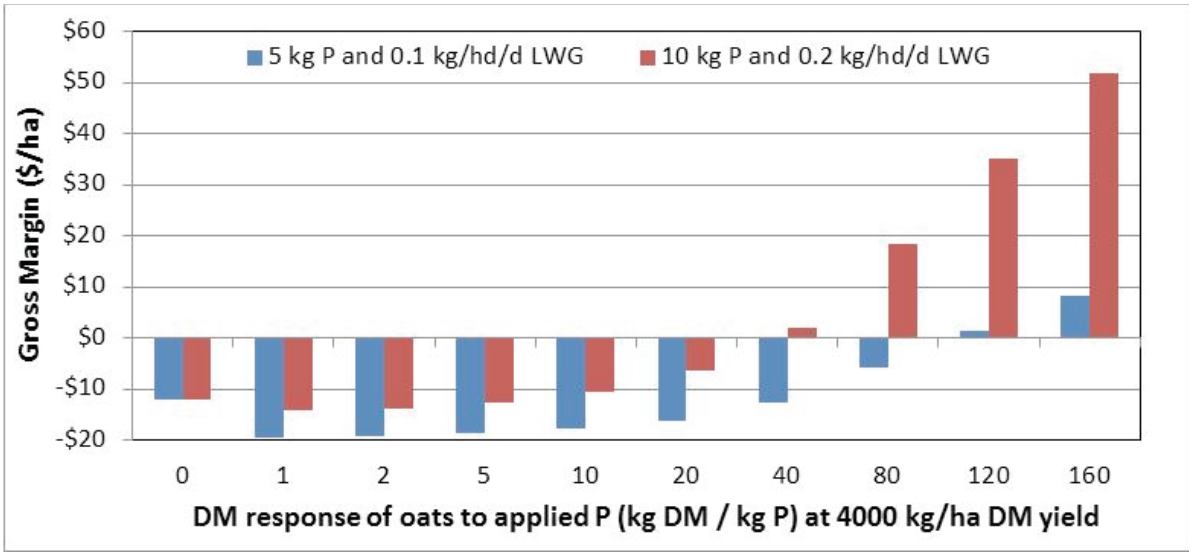

Figure 2. Gross margin for P fertiliser treatments and responses for oats

Oats – Nitrogen fertiliser

Unfertilised oats produced negative gross margins except for a slightly positive GM for the high producing site (Figure 3). The economics of unfertilised oats, at all levels of baseline productivity, were only made worse by the application of N fertiliser, unless the scenario included response rates of 50 kg DM/kg N and 0.2 kg/hd/d LWG at the higher producing sites.

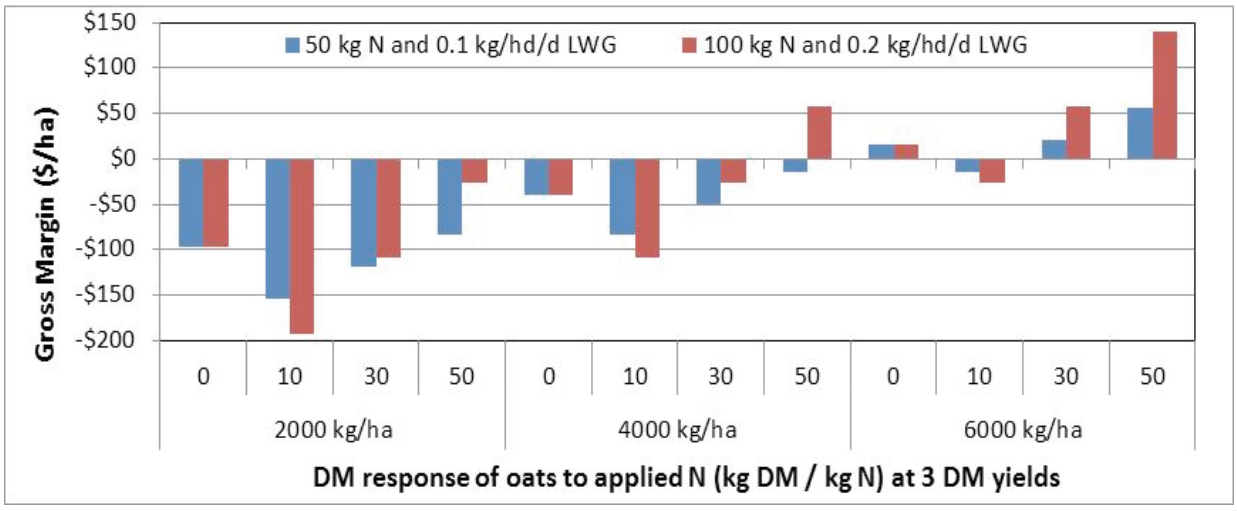

Figure 3. Gross margin for N fertiliser treatments and responses for oats

Discussion

This study indicates a lack of profitability of annual forages in the target region, and the inability of fertiliser to shift production to a profitable level. For oats there were some scenarios that provided a positive gross margin however these only occurred with a high plant response at a medium (4000kg/ha) or high (6000kg/ha) production site. However the only scenario that provides a positive gross margin with forage sorghum, albeit very small, is when 15000 kg/ha dry matter is grown without N fertiliser. Even the highest plant and animal responses didn't provide a profitable outcome. This indicates that fertilising forage sorghum is generally un-profitable under the animal response scenarios assumed in this study and that higher response or better price premiums are required to achieve a profitable outcome.

It is unlikely higher forage yield responses are biologically feasible for either crop. However, the magnitude of animal LWG responses to fertiliser is relatively unknown due to the paucity of past research into the impacts of fertiliser on diet quality. This analysis presumed applying fertiliser provides modest animal liveweight gain responses (0.05 kg/hd/d or 0.1 kg/hd/d) depending on the amount of fertiliser applied, whereas the main impact was to improve dry matter production and therefore stocking rates.

Conclusion

This desktop, modelling study demonstrates that the use of fertiliser is unlikely to generate extra profit from these forage crops. While some beef producers do use fertiliser, many have ceased growing annual forages. This analysis supports these actions and suggests that those producers fertilising annual forages may be better off considering alternative cropping or forage systems. Very high dry-matter and animal production responses in combination with lower costs associated with fertiliser application are required to make fertiliser application on annual forages in this region profitable. This study demonstrates land-managers in the northern region need to carefully consider and monitor both the production and economic responses from trial areas before paddock scale applications are implemented.

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Managing nitrogen nutrition under intensive cropping in low rainfall environments

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Abstract

In sandy soils of low fertility the need for increasing inputs of nitrogen (N) as the intensity of cereals increases is clear. Testing of N management strategies on dune, mid-slope and swale soils at Karoonda, South Australia over six different growing seasons ranging from decile three to ten rainfall, showed that yield was substantially improved by increasing N inputs (from 9 to 40 kg N/ha) on the sandy soils and that production was maintained at nil N input on the swale. However, analysis of net N balance supports the increasing concern that intensive, cereal-dominant cropping systems are drawing down on soil organic N reserves where N inputs are low. The inclusion of a legume based pasture break on this site had a measurable positive impact on both grain yield and N supply to subsequent crops. However, this increased N supply was over a limited timeframe. Therefore even with a legume based break, fertiliser derived N was required to maintain productivity. In low rainfall environments, deferring a significant proportion of the N input until later in the season when estimates of yield potential can be made with more certainty is an attractive concept for managing risk. However, testing of in-season N application over a range of seasons showed that some sandy soils that have been intensively cropped with cereals are so deficient in N that the benefit of eliminating early season N deficiency can outweigh potential efficiency gains from later in-season N application.

Key words

Soils, Fertiliser, Mallee, Nitrogen Supply Potential, Nitrogen Balance

Introduction

The intensification of cropping, particularly of cereals, in low-rainfall environments in Australia has been advocated as a management strategy that increases profit for growers. The low rainfall (< 350 mm annual rainfall) Mallee environment features dune swale systems with soil types that vary considerably in production potential within relatively small distances (Rab et al. 2009). The sandy topsoils associated with the dunes and mid-slopes are low fertility in terms of organic matter and nutrition, in particular nitrogen (N) and microbial activity. Microbial activity and N mineralisation to supply N to crops in these soils with low organic matter are largely dependent upon the quantity and quality of carbon inputs from crop residues and is often a yield limiting factor (Gupta *et al*. 2011). Cropping intensification can lead to a reduction in the frequency of legumes, which results in a decline in soil organic N reserves (Angus et al. 2006). The study presented here is one of very few involving multiple soil types in the Mallee land system and measuring net N balance over a long-term sequence. The aims of this study were to identify:

1. Optimal N input levels for each soil type considering long-term net N balance; and
2. Soil-specific strategies for increasing the yield and improving the N nutrition of cereals.

Method

Wheat crops were sown in May of 2010-2014 (following opening rains of at least 20mm) at Lowaldie (S 33°59.616, E 136° 19.915) 20 kms North East of Karoonda, SA. The agronomic treatments included volunteer pasture in 2010 followed by wheat managed with district practice fertiliser inputs (9kg N/ha and 10 kg P/ha applied as DAP at sowing) for the remainder of the experiment, and continuous wheat treatments with the use of nil fertiliser inputs, district practice fertiliser inputs, higher N inputs at sowing (40 kg N/ha with 10 kg P/ha) and higher N inputs split (9 kg N/ha at sowing and 31 kg N/ha first node with 10kg P/ha at sowing). The volunteer pasture had an approximate composition of 1.8-3.1 t/ha medic and 0.5-2.5 grass and broadleaf weeds and was spraytopped in spring but did not receive any other management intervention. The treatments were applied to 15 m long plots on four key Mallee soil types (swale, mid-slope, dune-crest and dune) and treatments were arranged in a randomised complete block design with four replicates. The difference between management strategies within a soil and season was analysed using ANOVA.

The soils were characterised for a range of properties given in Table 1. The swale had higher pH, organic carbon content, cation exchange capacity and mineral N content with lower water repellency than the other soil types and all soils had Colwell P status in the adequate range. All soils with a sandy topsoil layer (mid-slope, dune-crest and dune) had water repellency and low organic carbon. The dune-crest had the lowest plant available water capacity with no water extraction below 60cm depth (Table 1). The direct cause of this has not yet been determined.

Table 1. Key soil properties at the commencement of treatments in 2010.

Soil Property	Swale	Mid-slope	Dune-crest	Dune
Topsoil texture	Loam	Sand	Sand	Sand
[a]Soil pH (H_2O, 1:5), 0-10cm depth	7.4	6.6	6.3	6.3
[b]Colwell P (mg/kg), 0-10cm depth	39	30	28	25
[c]Organic Carbon (% w/w), 0-10cm depth	1.4	0.7	0.5	0.5
[d]Mineral N (kg/ha), 0-100cm depth	168	115	NA	57
N supply potential (kg N/ha/average growing season)	31.5	18.6	NA	12.0
[f]Plant Available Water Capacity (mm water/ 100cm depth)	116	110	31	120

Methodologies for assessment of soil properties are all available in Rayment and Lyons (2011);[a]4A1,[b]9B1, [c]6A1, [d]7C2b. [e]Analysed according to Burk and Dalgliesh (2008).

Soils from a subset of treatments were analysed using the N supply potential technique described in McBeath et al. (2015). Briefly, the technique is a measurement of microbial biomass N and N mineralised following a 21 day moist incubation where it is assumed that 50% of the microbial biomass N is available for plant uptake. The N balance for a given year was calculated as N balance (kg/ha) = N input (kg/ha)-N Yield (kg/ha) where, N Input= N fertiliser (kg/ha) + N supplied from legumes (kg/ha) + 10 kg/ha N from free living N fixation (Gutpa et al. 2006). N from legumes= 25% of N fixed in year prior (Ladd et al. 1986) assuming 20kg N/t dry matter is fixed (Peoples et al. 2009). N Yield= grain yield (kg/ha) x grain N content (protein/ 5.7). The net N balance is the cumulative outcome of yearly N audit for the five years of the experiment. The audit did not account for N losses through leaching, volatilisation or denitrification or differences in fertiliser use efficiency for different soils and seasons.

Results and Discussion

Yield

There was a notable absence of significant response to the N management strategies imposed over the five years of experimentation on the swale soil (Table 1). As discussed elsewhere, this supports the conclusion that reduced inputs on the swale soil type are feasible in this particular environment (Monjardino et al. 2013). Confidence in this strategy has grown in light of the lack of response to fertiliser input over five years with a range of season types from decile 3 to 10. However, the productive potential of this soil relative to the other soil types in the same paddock cannot be ignored and the effect of reduced inputs requires monitoring to ensure that production potential is not jeopardised. On the mid-slope soil, there was a difference between nil fertiliser and district practice (Table 2). Because the nil fertiliser did not receive any P inputs, it was not possible to determine with certainty whether the response was related to inputs of N or P, however soil P test results indicated that this soil should have been adequate for P at the commencement of the experiment (Table 1). On the dune-crest and dune soils, it was only with inputs of more N through fertiliser (at 40 kg N/ha) or a legume based pasture break that yields were significantly more than the nil fertiliser and district practice treatment. In 2013 and 2014, three and four years after the last pasture break, the effect of the pasture break on productivity was reduced to levels equivalent to district practice yields (Table 2). These results suggest that, in the absence of a major disease problem, N is a major driver of yield on these sandy soil types, and that repeated inputs at higher levels of fertiliser input are required to maintain productivity. The difference between supplying extra N in fertiliser at sowing compared with in-season was less consistent. Generally, the best yields were achieved with the extra fertiliser N applied at sowing, but in some instances there was no penalty for delaying to an in-season application (Table 2). The season type did not appear to drive the effectiveness of the in-season N application and in all cases the in-season N was applied with impending rainfall.

Nitrogen Supply Potential and Nitrogen Audit

Analysis of the two best yielding treatments showed that there was a greater potential supply of N in the year following a legume-based pasture break (2011) compared with increased inputs of N fertiliser at sowing (Figure 1). In the second year after the pasture break (2012), these differences were not significant (Figure

1). This suggests that the N related break benefit has a limited time span and is consistent with additional break crop experiments located at the same site (McBeath et al. 2015). Had the pasture treatment been more intensively managed (e.g. weed control and pasture sown for higher density) it is possible that more N related benefits would have been available for subsequent crops. Given 2010 was a decile 10 season it is possible that pasture production and resulting N fixation was well above normal levels but additional trials at this site measured comparable N derived break effects in later seasons (McBeath et al. 2015).

Table 2. Yield in response to season (2010-2014), soil type and management, including a volunteer pasture in 2010. Within a season and soil, the row is appended by a least significant difference (LSD) value. Yield in response to management strategies that differ by more than the LSD are significantly different (P < 0.05). The magnitude of the LSD for each soil and season illustrates the level of in-paddock variation that needs to be managed even within soil types.

Year	Nil Fertiliser	District Practice	High N Upfront	High N Split	Volunteer Pasture	LSD
			Swale			
2010	4.4	4.2	4.3	4.0		NS
2011	3.3	3.1	3.4	3.3	3.6	0.4
2012	2.8	2.7	3.2	2.9	2.8	NS
2013	1.4	1.4	1.3	1.4	1.5	NS
2014	2.7	2.8	3.0	3.0	2.8	NS
			Mid-slope			
2010	2.6	3.0	3.2	3.1		0.6
2011	2.7	3.1	3.8	3.6	4.5	0.4
2012	1.2	1.7	2.4	1.7	2.4	0.4
2013	1.0	1.3	1.8	1.8	1.6	0.3
2014	2.0	2.5	3.5	3.5	2.6	0.4
			Dune-crest			
2010	0.8	1.1	1.7	1.4		0.5
2011	0.8	1.0	2.1	1.4	2.9	0.4
2012	0.4	0.4	0.8	0.5	0.9	0.3
2013	0.3	0.4	0.8	0.7	0.6	0.2
2014	0.5	0.8	1.6	1.3	1.1	0.4
			Dune			
2010	1.4	1.4	2.0	2.0		0.6
2011	1.8	2.0	2.9	2.5	2.8	0.4
2012	0.9	0.8	1.5	1.3	1.2	0.4
2013	0.6	0.9	1.6	1.6	1.1	0.4
2014	0.8	1.1	2.1	1.8	1.2	0.4

X shaded cells denotes significantly greater than nil, X shaded cells denotes significantly greater than nil and district practice.

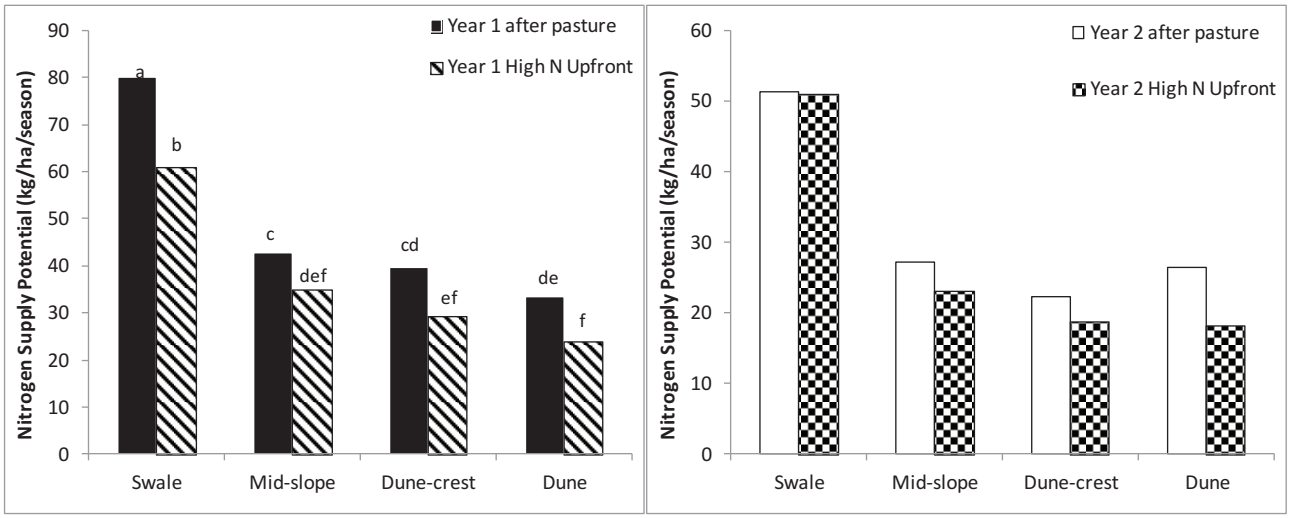

Figure 1. Nitrogen supply potential (kg N/ha/average growing season) in response to treatments with higher N inputs on key Mallee soil types. In Year 1 at P 0.05, LSD between treatments was 8.7 kg/ha/ growing season while in Year 2 P >0.05. A column appended by a different letter is significantly different from another.

An audit of N inputs and outputs highlighted that while productivity on the swale was maintained without additional inputs of N, the N balance was negative and soil organic N reserves were likely being depleted. An alternative view is that there could have been movement of N from the dune to the swale that has supplied N to maintain crop production on these soils, but this has not been confirmed by measurement. The low N input

treatments (over the five year period) resulted in a negative balance for N on the mid-slopes with a neutral balance at 40 kg N/ha input. On the low yielding dune-crest, the N balance was positive for all levels of fertiliser N input and up to 117 kg N/ha. This is indicative of the presence of other constraints to production (e.g. soilborne diseases) on this soil type preventing utilisation of the N applied. On the dune, there was a positive N balance for high inputs of N at 54-60 kg N/ha over the five year period.

Table 3. The net N balance (kg N/ha) following five year implementation of treatments on key Mallee soil types. Within a soil (row) at P 0.05, LSD between treatments was 34 kg N/ha and a treatment annotated with a different letter is significantly different from another.

Soil	Nil Fertiliser	District Practice	High N Upfront	High N Split	Volunteer Pasture
Swale	-210 d	-156 c	-82 ab	-61 a	-102 b
Mid-slope	-102 b	-81 b	-5 a	10 a	-92 b
Dune-crest	-22 c	23 b	91 a	117 a	-24 b
Dune	-64 c	-15 b	54 a	60 a	-21 b

Conclusions

Cereals grown on sands showed continued responses to N inputs at levels higher (40 kg N/ha) than district practice (9 kg N/ha) while heavier soils on the swales maintained production with nil or low N input, but a net N audit suggests the possibility of a significant decline of soil N reserves at this level of inputs. Break effects derived from legume based pastures only lasted for up to two years. As a result maintaining N in the system using N inputs of fertiliser and/or legume based breaks is required on sandy soils in the Mallee to maintain production.

Acknowledgements

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Nitrogen management: a key driver of farm business profit and risk in the low rainfall Mallee

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Abstract
The use of cereal-intensive rotations in the low rainfall Mallee region has resulted in nitrogen (N) fertiliser inputs becoming an increasing cost and risk for farm businesses. Five years of on-farm research near Karoonda in the South Australian Mallee has demonstrated advantages in shifting N fertiliser investment from some soil types to others but farm level profit-risk analysis was required. The impact of N fertiliser and residue based management practices on the profitability and the exposure to risk of a 'model' farm business was evaluated with local farmers, consultants and researchers over two workshops using a profit-risk decile calculator. Increasing N fertiliser inputs on all soil types dramatically increased annual farm profit in the better seasons (decile 6-9, 254-33 mm growing season rainfall), however in poorer seasons (decile 1-3, 159-201 mm rainfall) losses were greater. When N inputs were adjusted according to soil type, profit upsides were captured without increasing exposure to downside risk. Further analysis of the Karoonda model farm showed that the move towards more intensive cereal cropping in low rainfall (<350 mm) environments increased business risk when compared with a sequence including a pasture phase, even when risk management practices such as soil-specific N application were practiced. At higher cropping intensity, financial losses in poor seasons were more. While high cropping intensity increased potential business profitability in better seasons, the maximum fertiliser rates (~80 kg urea ha^{-1}) that workshop participants were willing to apply are likely to constrain yields, and therefore profitability, in higher rainfall seasons. This risk-related constraint to the amount of fertiliser that can be applied is important when evaluating the role for legume based breaks to supplement or replace N inputs from fertiliser.

Key words
Soil specific, sequence, break, legume, nitrogen, fertiliser, profit

Introduction

Farmers have widely adopted the use of intensive cereal based rotations in south-eastern Australia's low rainfall (<350mm) Mallee region. While these rotations were shown to be profitable (Sadras and Roget 2004), paddocks are now increasingly suffering from declining water use efficiency following a lengthy sequence of cereals. In the south Australian Mallee at Karoonda (337 mm of annual rainfall), a range of N management strategies have been compared across variable soil types in the dune-swale landscape. Volunteer medic based pastures increased subsequent wheat production for two years, and was largely related to N inputs from the legume (McBeath *et al*, 2015a, b). In an intensive cereal sequence, additional N (applied as urea) at sowing increased yields compared with district practice across the sandy mid-slope and dune soil types, while on the constrained 'heavy' swale soil increased yield from additional N inputs were not observed (McBeath *et al*, 2015b). A similar conclusion was reached in a profit-risk modelling study conducted for the same region (Monjardino *et al*., 2013) These data provide strong support for the use of soil-specific N management practices (e.g. variable rate application) in Mallee paddocks. However, even with efficient N fertiliser management practices in place, local farmers and consultants are concerned about the long-term viability of business employing intensive cropping systems with high input costs and local research has indicated that legume based breaks can provide significant N related benefits (McBeath *et al*, 2015a). In 2014, we worked with farmers and consultants from the South Australian Mallee to evaluate the impacts that the N management research undertaken at Karoonda would have on farm business profitability and exposure to downside risk.

Methodology

Two workshops were held in 2014 with farmers and advisors from the southern South Australian Mallee region. During the workshop, participants developed a model farm that was representative of the Karoonda region. The key physical attributes of the model farm developed by the participants included:

- Total arable farm size of 2400 hectares
- Enterprise mix of 85% cereal, 15% canola (intensive cropping)
- Two labour units drawing $50,000 per unit plus $20,000 allocated to casual labour
- Farm equity of 72%
- Plant and machinery inventory of $780,000
- Total fixed costs of $77,000

The profit-risk decile calculator developed by Ouzman et al (2015) was used to compare N management scenarios on business profitability and risk of the Karoonda model farm. A key feature of the calculator is the ability to compare alternative strategies across the full range of growing season deciles (here defined as decile of growing season rainfall plus 0.25 fallow rainfall) using a range of financial and economic measures in the same analysis. We conducted scenario analysis to investigate the effects of site-specific N management and the level of cropping and pasture intensity on farm business profit and risk. The first analysis compared three N fertiliser management scenarios on the default farm based on intensive cropping, farm with an enterprise mix of 85% cereal and 15% canola (including fixed low input (30 kg urea/ha) on all soils, fixed high input (80 kg urea /ha) on all soils, and soil-specific input (80 kg urea/ha on the dune (deep sand), 40 kg urea/ha on the mid-slope (sand over clay), and 20 kg urea/ha on the swale (loam over clay)). Canola was sown to the heavier soil types (45% mid and 55% swale). The N management scenarios were applied only to the cereal enterprise of the model farm. All other inputs, including phosphorus fertiliser, were kept constant across each scenario. A combination of trial data, bio-economic modelling as well as farmer and consultant experience was used to develop a matrix of cereal crop yields for each combination of N management practice x soil type x season decile (Table 1)

Table 1. Wheat yield (t/ha) in response to N management strategy, soil and season type (decile) for the Karoonda model farm producing 2040 ha of wheat and 360 ha of canola. Yields were developed using farm records, local trial data and APSIM outputs.

N management	Soil	Decile 1	Decile 3	Decile 5	Decile 7	Decile 9
Fixed Low Input	Dune	0.2	0.4	0.8	1.2	1.8
30 kg urea/ha all	Mid	0.5	1.1	1.9	2.1	2.5
	Swale	0.1	1.1	2.0	2.9	4.0
Fixed High Input	Dune	0.2	0.8	1.6	2.2	2.8
80 kg urea/ha all	Mid	0.5	1.1	2.2	3.1	3.5
	Swale	0.1	1.1	2	3.5	4.5
Soil Specific Input	Dune	0.2	0.8	1.6	2.2	2.8
80 Dune, 40 mid, 20 swale	Mid	0.5	1.1	2.2	2.6	3.1
kg urea/ha	Swale	0.1	1.1	2.0	2.9	4.0

The second analysis compared the soil-specific input scenario of the high-intensity cropping (default) farm with a similar soil-specific strategy of a lower crop intensity model farm, which involved producing 720 ha of self-regenerating annual legume pasture (largely allocated to lighter soil types, 30% dune, 60% mid, 10% swale) and a 750 ewe self-replacing merino sheep enterprise. In the pasture situation 720 ha of the wheat was assumed to follow a medic based pasture and yield benefits aligned with research outcomes at Karoonda were assumed (McBeath et al. 2015 a,b) and no urea was applied.

Results and Discussion

By increasing N fertiliser inputs from 30 to 80 kg urea/ha on all soil types, there is the potential to dramatically increase annual farm profit in the better seasons (Decile 7-9). However, in poorer seasons (decile 1-3) farm losses were approximately $60,000 greater under the high N input strategy (Figure 1a). Therefore adopting a high input fixed N strategy would increase financial risk of the model farm in poor seasons. When the soil-specific N input strategy was compared to the low N input scenario, the analysis showed that potential profit upsides were able to be captured without increasing the exposure to downside risk.

Soil Specific N was more profitable than Low N in all season types except for a decile 1 season (-$14,000). Importantly, the soil specific N management strategy was still able to capture large profit advantages of $110,000 – $183,000 over the low input fixed N strategy in decile 5-9 seasons (Figure 1a). While the ability of a business to accommodate a given level of loss will vary between businesses, a key finding in this analysis was that margins for profit could be quite small, even in a decile 5 season (eg. 93,000 to 203,000, Figure 1a). Therefore the ability of the business to recover from losses is heavily reliant on above average rainfall and any strategy that minimises downside risk in lower rainfall seasons is important for business resilience.

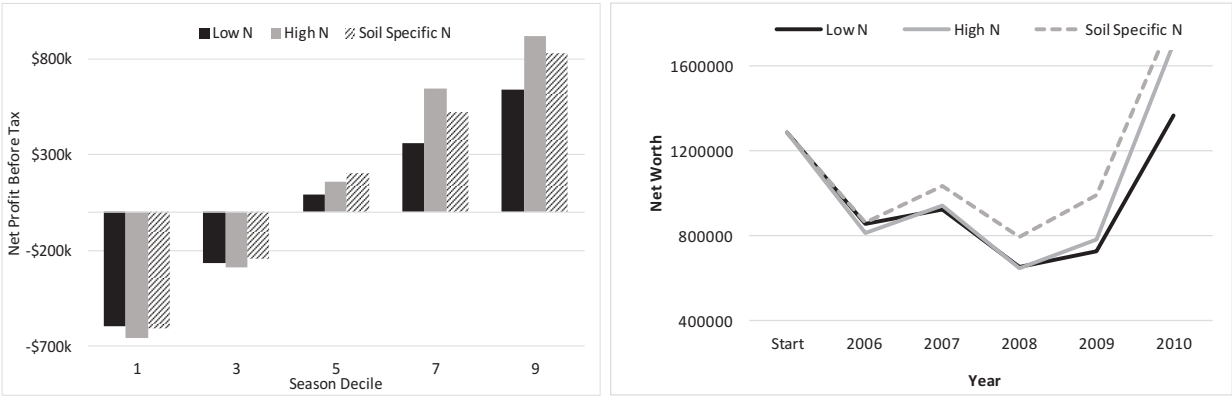

Figure 1.a (left) Annual farm net profit before tax across season type and b. (right) on farm net worth across a selected run of seasons for fixed low urea input (30 kg/ha in all soils), fixed high urea input (80 kg/ha in all soils) and soil-specific urea input (80 kg/ha on the dune, 40 kg/ha on the mid-slope, and 20 kg/ha on the swale) nitrogen management scenarios on a 2400 ha farm producing 2040 ha of wheat and 360 ha of canola. Growing season rainfall deciles were 2 (2006), 5 (2007), 3 (2008), 5 (2009), 10 (2010).

The three N input scenarios were compared across a period of five seasons (2006-2010), where a wide range of growing season rainfall deciles was experienced at Karoonda (Figure 1b).. The farm net worth of the model farm implementing the fixed low and high N input scenarios tracked similarly over this period. However the net worth of the farm adopting the soil-specific N management strategy was higher due to its ability to capture increased profits in good years and minimise losses in poorer seasons. At the end of the five year period, the farm implementing soil-specific N management had increased its net worth by $548,000 while the fixed low N input farm gained only $80,000 over the same period (Figure 1b). The high N scenario increased net worth by $419,000 over the five year period but was performing well below the soil specific N scenario in the lower rainfall seasons of 2008 and 2009 ($147,000 to $207,000 less) (Figure 1b).

Analysis of the Karoonda model farm also showed that the move towards intensive cereal cropping in low rainfall environments increased business risk, even when risk mitigation practices such as soil-specific N application were practiced. The losses made by the intensive cropping farm were $195,000 greater in a decile 1 season than the losses incurred on the farm with pasture. While the returns are greater in better seasons, the income forgone in a decile 9 year by the pasture-based systems ($99,000) is less than the losses saved in a decile 1 season (Figure 2).

The results shown in Figure 2 suggest that there is scope to re-evaluate the role of regenerating pasture phases to manage profit-risk and farm level fertiliser N requirements. During the workshops, farmers highlighted the fact that they were not comfortable with the risks associated with the high inputs required to sustain continuous cropping and that many were not willing to apply more than 80 kg/ha of urea in any season, which is likely to constrain crop yields in higher rainfall seasons. This analysis demonstrates that while the upside (profit in the higher rainfall years) is higher with intensive cropping, incorporating a pasture phase does not necessarily result in an unprofitable business and arguably it is a strategy that improves business resilience by reducing losses in lower rainfall seasons.

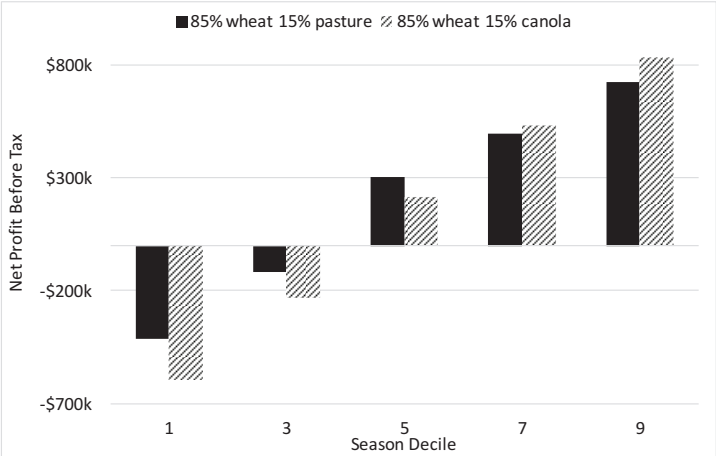

Figure 2. Annual farm net profit before tax in response to season type for a farm with 720 ha of Pasture and 1680 ha of wheat where no N fertiliser is applied to the 720ha of wheat that follows pasture and soil specific inputs of 80 kg/ha urea on the dune, 40 kg/ha urea on the mid-slope, and 20 kg/ha urea on the swale applied to 960 ha of wheat compared with the intensive cropping scenario of 2040 ha of wheat and 360 ha of canola with soil specific inputs of urea.

Conclusion

We have demonstrated that it is possible to analyse the potential effect of implementing research outcomes as farm practices at the farm level using a profit-risk decile analysis in a workshop setting. This analysis delivered outputs that are meaningful to growers and advisers, in terms of their motivation to adopt a practice on farm. A uniform increase in N fertiliser rate increased annual farm profit in the better seasons (decile 6-9), however losses were greater in poorer seasons (decile 1-3). When N inputs were adjusted according to soil type, profit gains were captured in better seasons without increasing exposure to downside risk in poor seasons. Analysis of the Karoonda model farm also showed that a more cropping intensive system carried a higher level of business risk, even when risk mitigation practices such as soil-specific N application were practiced. Consequently, there is an opportunity to re-evaluate the role for legume pasture phases to manage N inputs and business resilience in low rainfall Mallee farming systems.

Acknowledgments

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Postnormal thinking: The need for a better understanding of what oil vulnerability will mean for Australian agriculture

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Abstract
Industrial agriculture uses fossil fuels for the production, processing and transport of agricultural commodities enabling significantly increased volumes and diversity of food/products and markets. Whilst a proportion of this is post-farm, with four tenths consumed at the household/supermarket level, the integrated systems of industrial food production binds the farmer to the consumer via long-chain production and supply systems as well as global economic markets. It is likely that our global economy will begin to feel the supply pressures as stocks of conventional and non-conventional as oil decline (and climate) challenges lead to the constraints on their use later in this decade or early in the next. This will have economic impacts either side of the farm gate. The resilience of the production methods and long chain systems in modern agribusiness to oil shocks and prolonged price increases/fluctuations has not been adequately researched and could present significant risks to the viability of current rural production and communities. It would make for prudent risk management for there to be a dedicated program of research that better understands energy use in agricultural production, including agronomy, which identifies possible risks and considers how to build resilience into Australia's food and fibre production systems. This knowledge could become both economically and societally very valuable**.**

Key words
Rural, peak oil, oil vulnerability, agriculture, agronomy, policy failure, governance, research.

Introduction

It could be argued that in terms of the emerging impacts of climate change and energy we are entering the period of the postnormal, described by Funtowicz and Ravetz as where, "… facts are uncertain, values in dispute, stakes high, and decision urgent" (Funtowicz, 1993). For example, we have built a complex society, even a civilization, based on ever increasing access to a hydrocarbon rich, flexible and scalable energy source drawing from (and returning waste to) an increasingly degrading environmental sphere; which is altering existing energy transitions and flows. The notion of limits by the very nature of our expansion requires recognition of that postnormal world and the development of thinking and science to better inform our adaptive responses (Sadar, 2010; Montuori, 2011). The capability to frame serious consideration of research around agriculture and rural communities within a postnormal framework that takes a risk based approach is one of the major challenges facing us in terms of effective governance and policy (Poldy, 2003).

Method

This paper aims to act as a discussion paper to introduce the topic of energy use in agriculture, oil vulnerabilities and economic and social ramifications. It is built out of my Masters Research thesis, *Peak oil and oil vulnerability: what are the implications for industrial agriculture and rural communities?*, which included a case study based in the southern gulf region of Queensland, and looks at the situation around possible constraints to the supply of conventional and non-conventional oil, implications arising, the Australian policy context and then identifies the broad areas of possible research and development. It raises the risk of inadequate understanding of energy vulnerability for agriculture (and agronomy) and the lack of a research focus based around the depletion of oil as a primary energy input to agriculture.

Oil vulnerability

To date we have seen close to a decade of plateauing of production, with both high and low oil prices acting as both incentive and disincentives for the development of new fields. Whilst an upturn in discovery and production of non-conventional oil has occurred, given the IEA estimates of the conventional oil peak (2006) and decline of already discovered oil, the continuation of the plateau of is unlikely in the longer term (International Energy Agency, 2010). Estimates of the potential date(s) for the roll-over, being the point where conventional oil supply can no longer be maintained, generally sit within a band between 2010

to 2020 (Coventry, 2014, P.16.). A recent study by the Energy Watch Group sees a rollover somewhere between 2015 and 2020, with world oil production declining by 40 percent by 2030 (Zittel et al., 2013); with an estimated annual depletion rate of around 4-6% (International Energy Agency, 2011). Given the possible correlation of energy use to GDP this could pose significant economic and social risks (Ayres and Warr, 2010; Kumhof and Muir, 2012). New technology and methods have allowed for the significant further resource development of unconventional oil and gas fields, particularly in the United States of America, however analysis points to this resource growth peaking and going into rapid decline sometime around the latter part of this decade (Hughes, 2014). Even though the timeframes and rates of decline will be impossible to accurately predict given geography, geology, geopolitics and economics, we can be certain that decline will take place and given agriculture's reliance upon fossil fuel inputs this event will have significant implications for both agriculture and rural communities.

Energy use in agriculture

Whilst we have seen the development of alternative and boutique farming methods and markets, especially in southern Tasmania, the majority of agricultural production in rural Australia is still engaged in larger scale industrial agriculture (Barr, 2005, ABARES, 2015). Food production, in western industrial systems, relies upon the input of fossil fuel for the production, processing and transport of agricultural commodities. This has enabled greatly increased volumes and diversity of food/products, and facilitated the development of a wider mechanism and structure for distribution to global markets that offers to consumers a vast range of commodities, ignoring externalities, at relatively cheap prices. The introduction of chemical fertilizers, insecticides, plant genetics and the development of mechanisation have enabled farmers to increase production via scale, crops, harvesting and mechanical transport. Beyond the farm gate an industry of processing has turned that farm output into a wide array of products, process and markets. Whist a proportion of this is post-farm gate, with upwards of four tenths of this consumed at the household/ supermarket level, the integrated systems of industrial food production binds the farmer to the consumer via long-chain production and supply systems as well as global economic markets. So dependent modern industrial agriculture become on energy that it requires an input of between seven and ten calories of fossil fuel input for every calorie of food produced (Pimentel and Giampietro, 2008)**.** Knowledge of energy use in agriculture is generally well understood but it is almost universally taken as a given, is viewed in isolation and not considered in the context of either its wider role in maintaining an industrial system or in the context that energy costs or availability may change. If energy transition is considered it is usually in the context of response to climate change. Energy usage in agriculture is only a component of factors for change and development in agriculture, which will be also driven by economics, political philosophy and technology. Farmers have adapted to changes and hydrocarbon use, both in the use of new products but also in response to increased energy costs. Sloan et al point out that often in response to increased fuel prices US farmers have switched to more efficient methods, that Australian data is too aggregate to "…reliably describe similar trends…', but conclude that parallel energy efficiencies are likely for Australian farmers (Sloan et al., 2008, p.7; Miranowski.J., 2005). However the possible rate of change in hydrocarbon based energy supply could present difficulties for farmers, food security and rural communities. For example my research pastoralist interviewed reported that they felt that significant increases in the price of diesel could make their businesses unviable (Coventry, 2014, P. 61-63.). It is reasonable to conclude that given a consistent period of advances in energy efficiencies in mechanics, processes and production that diminishing returns on the current agricultural systems could be expected.

Implications for agriculture and rural society

The evolution of the current energy dense model and systems has taken place over decades and has, via a neoclassical economic framework, built in energy and structural mechanisms that will face significant challenges operating at higher energy prices, lower energy profit ratios or circumstances of shocks or shortages. These can range from fuel and fertiliser supply issues, vulnerabilities in long chain systems, failure of markets (existing and emergent), increased debt vulnerability, distance, isolation and service provision and a range more beyond the scope of this paper to identify. Rural communities have seen the centralisation of services, the decline of rail transport and the reduction of population beyond regional centres. The resilience of the long chain systems in modern agribusiness to oil shocks and prolonged price increases has not been fully researched and presents a significant risk to the viability of current rural production (Sloan et al., 2008). Any shortages of, or significant increases in the price of, fuels and feedstock (fertilizers and pesticides) could hurt rural production and rural communities directly. For example analysis by Sloan et al has identified

that possible changes due to oil vulnerability may bring about the following changes: (a) to the distribution of agricultural types within Australia's regions; (b) to the intensities of agricultural land uses; (c) shifts in the primary mode of transportation of agricultural products, such as from road to rail; (d) restructuring of settlement patterns – concentration or dispersal – as communities adapt to higher transport costs; and (e) abandonment of some land types or sub-regions if production and transport costs became prohibitive (Sloan et al., 2008 , p.11). This challenge is not limited to established industrialised agricultural systems, for example the dependence of developing countries, such as China (Smil, 1991, p.586), on increasing fertiliser use to feed ever increasing population growth (Giampietro and Pimentel, 1993).

Policy avoidance

Whilst there have been limited attempts to raise the issue of oil vulnerability into the political and policy discussion spheres there has been an unwillingness to openly consider what the implications for Australian society may be. This tension has in part led to "… a petroleum security policy stasis in which obscuration or deferment of problem acknowledgement substitutes for the formulation of a response" (Dodson and Sipe, 2010, p.294). For example, at the time of writing, the Agricultural Competitiveness Green Paper contains one small line on energy security, being that the, "… Government will consider Energy Security, which may impact on Australia's food production, in the context of the Energy White Paper", with the final Agricultural Competitiveness White Paper is completely silent on energy risk (Department of Agriculture, 2014, P. 109; Department of Agriculture, 2015). The 2015 Energy White Paper is also silent upon both our rapidly diminishing indigenous conventional oil supply and upon any analysis of future global supply trends, either positive of negative, rather looking towards the analysis of the 2011 National Energy Security Analysis which sees no supply challenges out to 2035 (Department of Industry and Science, 2015). It is this failure to consider and analyse emerging risk that increases vulnerability and limits measures for either mitigation or adaptation. This places policy development in a weakened position, in a complex and often misaligned or crowded planning framework where issues and policy responses compete, cancel or confuse appropriate development. Academic research and community input can inform policy settings, as is with the increasing peer reviewed papers around peak oil, however both research and policy development can be supressed or hindered by a lack of, or even hostile, philosophical environment within government departments (Steele and Gleeson, 2010). Public servants and policy writers may have to wait for clear authorising environments to begin to even broach difficult topics. Until appropriate signals for research and policy development are available, Australia will be at increased risk of planning failure in regards to this event and its ability to effectively implement timely mitigation and adaptation measures.

Research needs

Current analyses of agricultural trends are located within the conceptual framework that cheap and plentiful oil and gas will continue and is almost the universal default position for both research and policy discussion. Any new work in relation to this issue is limited and exploratory. Research that begins to engage with an energy depletion component would mean that we are better informed to make appropriate policy development and improved adaptive responses. Whilst any of the above listed possible changes by Slone et al offer a starting point, baseline analysis of key vulnerabilities in relation to agriculture and rural communities is a solid starting point. These could entail research and analysis of key areas, including:

- energy inputs to and use in industrial agriculture and agronomy,
- what conventional oil depletion would mean for agricultural production and possible adaptation/transition pathways,
- transport and communication options and alternatives,
- how could rural society keep connected, active, engaged and viable in an energy constrained situation, what services and structures will fail and what will need to be replaced or restructured,
- methods for building community resilience and social cohesion.

These are but a small part of what should be an urgent and significant priority for future agricultural research. In general any further research will add in some form to further understanding of what will be, and how we can attempt to manage, that energy constrained and oil vulnerable future. Academia has to date played an undeveloped role in this task with limited work by a range of scattered and committed academics. It is not recognised in Australia in any tertiary curriculum as a key discipline, theme or serious area for either research funding allocation or research. Compared to other key societal challenges, for example climate change, an event of this impact is barely acknowledged and understood. The value of this research is not diminished whether the depletion period or roll-over commences towards the end of this decade or two

decades hence. Universities, agencies and research funding bodies that initiate this research will not only be providing an extremely valuable societal good but also will have information, understandings , skills, tools and product that will be globally needed, sought-after and valued. That knowledge generated may assist in the advancement of policy development by creating a pathway for a clearer authorising environment for policy writers which in turn may lead to better governance outcomes.

Conclusion

It is likely that little adaptive response to oil vulnerability will take place until we are truly in the postnormal space of depleting supplies. There exists the need for research and planning frameworks to be established that enable us to actively understand and negotiate those future complexities and challenges and be armed with the best knowledge to inform both mitigation and adaptation pathways. Given modern agriculture's role of assisting in the feeding of our global population such engagement and research should be of the highest priority.

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Improving WUE of canola in central NSW

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Abstract
Twelve experiments were conducted in central New South Wales to assess the response of canola to increasing amounts of available nitrogen (N) at sowing. Applied N varied across experiments, ranging from nil to 200 kg/ha, available mineral N at sowing ranged from 31 to 423 kg/ha. The response to applied N was positive in 10 of the 12 experiments, with a diminishing response in most experiments as the applied N rate increased. No experiment resulted in a negative effect of increasing N rate on grain yield. Nine of the 12 experiments did however result in a negative effect of increasing the applied N rate on grain oil concentration. Increasing the level of available N improved Water Use Efficiency (WUE) outcomes from an average of 8.6 kg/ha.mm-1 where no N was applied, to 11.1 kg/ha.mm-1 where the maximum N rate was applied. This combined with knowledge of regional soil N reserves and regional N application practices suggests that WUE outcomes of canola could be improved by increasing N availability to the crop.

Key words
Nitrogen, water use efficiency, grain yield, grain oil concentration

Introduction

In the early years of canola cultivation in central NSW crops were often planted after a legume pasture phase where soil N reserves were high. With more intensive cropping now implemented, there is a greater requirement for fertiliser N to optimise grain yield outcomes. There are several reports of the negative effects of excess soil N on wheat yield, often referred to as 'haying-off" (Taylor 1965, Dann 1969, van Herwaarden *et al*. 1998). However, there is little such evidence of 'haying-off' occurring in canola. Hocking and Stapper (2001) showed in experiments conducted over two seasons in southern NSW that 'haying-off' occurred in wheat but not in canola. Despite this, there is still a general concern among growers and agronomists that excess N application to canola can lead to excessive vegetative growth and water use that then limits water availability for pod fill. In central NSW (especially in western parts) cereal crops are often managed conservatively to 'ration' stored water over the growing season, and many growers attempt to employ these same practices for canola production.

Analysis of soil tests results by Incitec Pivot's Nutrient Advantage Laboratory Services in 2012 (Laycock 2012, unpublished) showed that in eastern-Australia 80% of soils had available mineral N levels less than 60 kg/ha. Combined with this, the amount of applied N in the experimental region is still on average quite low, from approximately 25 kg/ha in lower rainfall environments (e.g. Nyngan) to 50 kg/ha in more favourable environments (e.g. Wellington) (D McCaffery, pers. comm.). 'Rules of thumb' indicate that canola requires 80 kg/ha of available N per tonne of grain produced, so on average the amount of available N (assuming 50 kg/ha mineralisation of N within the growing season) would limit canola yield to 1.7 t/ha at Nyngan and 2 t/ha at Wellington.

The experiments reported in this paper investigate the response of canola to increasing N application combined with mineral N available in the soil at sowing. The results are reported as grain yield and grain oil concentration, as well as the effect on WUE outcomes in the region.

Methods

Twelve experiments were conducted from 2012 to 2014 at several sites across central NSW (Table 1). Nitrogen rates applied at sowing ranged from nil to 200 kg/ha N and mineral N reserves (at sowing) ranged from 31 to 233 kg/ha (to 90 cm depth). Varietal entries varied but are reported either as the main effect of N rate in experiments where no TT varieties were grown or as the non-TT hybrid variety where several varieties, including TT types, were grown. Reporting this way gave the greatest opportunity to maximise WUE outcomes.

WUE is calculated as:
WUE (kg/ha.mm^{-1}) = Grain yield (kg/ha) / (1/3 * fallow (November-March) rainfall (mm) + in-crop (AprilOctober) rainfall (mm) – 100 mm (evaporation))

Table 1: Site details including nearest town; rainfall received in the fallow period (November-March); rainfall received in-crop (April-October); available N at sowing, and varietal entries for 12 canola nitrogen experiments conducted from 2012 to 2014 in southern and central NSW.

Season	Site	Rainfall Nov-March (mm)	Rainfall Apr-Oct (mm)	Available N (kg/ha)	N Applied (kg/ha)
2012	Coonamble	618	132	156	0, 25, 50, 100
2012	Gilgandra	545	211	62	0, 40, 80
2012	Nyngan	465	87	100	0, 30, 60
2012	Trangie	396	135	112	0, 25, 50, 100
2012	Wellington	487	220	54	0, 40, 80
2013	Nyngan	110 (LF*)	189	180	0, 30, 60, 120
2013	Peak Hill	162	245	64	0, 50, 100, 150, 200
2013	Trangie	119	211	86	0, 30, 60, 120
2013	Wellington	255	230	223	0, 50, 100, 150
2014	Ganmain	100	270	60	0, 20, 40, 80, 160
2014	Geurie	295	256	93	0, 50, 100, 150, 200
2014	Tullamore	270	215	95	0, 50, 100, 150, 200

* Nyngan in 2013 was planted after a long-fallow period of 18 months.

Results and discussion

Grain yield and grain oil concentration

Grain yield responded positively to applied N in 10 of 12 experiments (Figure 1), with a diminishing response in most experiments as applied N rate increased. The two experiments that had no response to applied N, Coonamble in 2012 and Wellington in 2013, had a strong N background with 156 kg/ha and 223 kg/ha mineral N available at sowing respectively. There was however a positive response to applied N at Nyngan in 2013 which had strong N reserves (180 kg/ha). Across all experiments, there were no examples where grain yield was significantly reduced due to the application of N. In effect there was no evidence of canola 'haying-off' as has been reported in wheat crops.

There was however a reduction in grain oil concentration in 9 of the 12 experiments as available N increased (Figure 2). In two of the three experiments where there was no effect of increasing N availability on grain oil concentration, the grain oil concentration was low (<40%) at all N levels. In comparison to the grain yield response to applied N which diminished at higher N rates, the reduction in grain oil concentration was significant in most experiments at all levels of applied N.

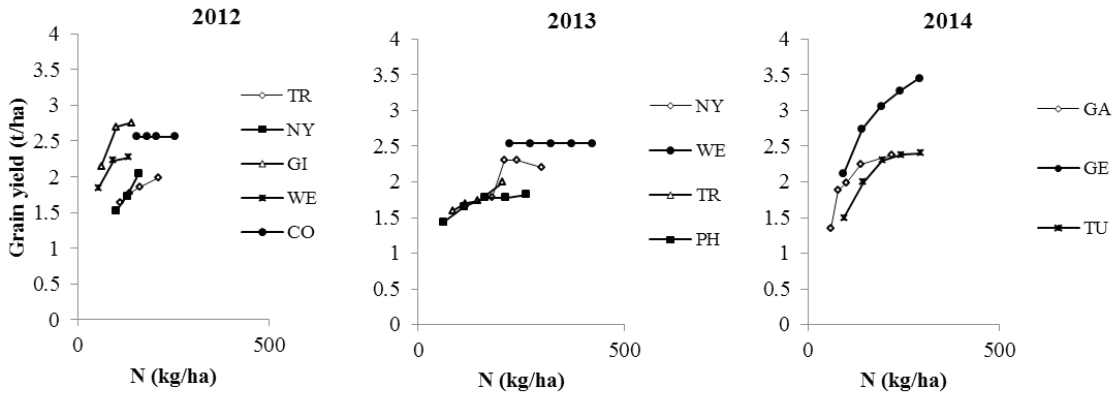

Figure 1: Grain yield response to available N (mineral N available at sowing plus N applied at sowing) at Trangie (TR, l.s.d.=0.2), Nyngan (NY, l.s.d.=0.13), Gilgandra (GI, l.s.d.=0.07), Wellington (WE, l.s.d.=0.12) and Coonamble (CO, n.s.) in 2012; Nyngan (NY, l.s.d.=0.21), Wellington (WE, n.s.), Trangie (TR, l.s.d.=0.08) and Peak Hill (PH, l.s.d.=0.12) in 2013; Ganmain (GA, l.s.d.=0.12), Geurie (GE, l.s.d.=0.12) and Tullamore (TU,

l.s.d.=0.13) in 2014

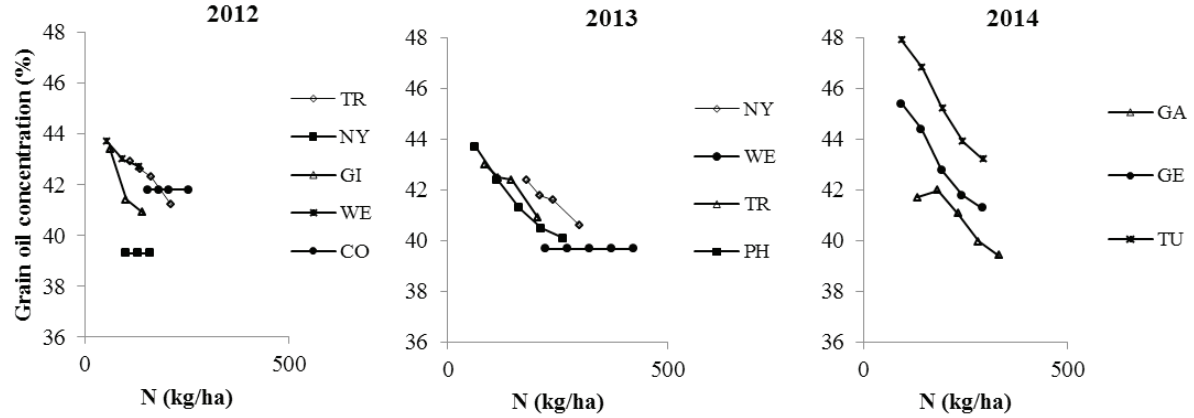

Figure 2: Grain oil concentration response to available N (soil mineral N plus N applied at sowing) at Trangie (TR, l.s.d.=0.4.), Nyngan (NY, n.s.), Gilgandra (GI, l.s.d.=0.2), Wellington (WE, l.s.d.=0.6) and Coonamble (CO, n.s.) in 2012; Nyngan (NY, l.s.d.=0.4), Wellington (WE, n.s.), Trangie (TR, l.s.d.=0.5) and Peak Hill (PH, l.s.d.=0.5) in 2013; Ganmain (GA, l.s.d.=0.5), Geurie (GE, l.s.d.=0.7) and Tullamore (TU, l.s.d.=0.5) in 2014.

Water use efficiency

Robertson and Kirkegaard (2005) reported on 42 experiments that were managed to achieve maximum yield potential in an equi-seasonal rainfall environment, finding an average WUE of 11 kg/ha.mm^{-1}. In the 12 experiments reported here, only two experiments (Wellington 2013 and Coonamble 2012) achieved a WUE above 11 kg/ha.mm^{-1} where no N was applied, with these sites both having a high level of mineral N at sowing (233 and 156 kg/ha N respectively). Where the N rate applied increased to the highest rate in each experiment, 7 of the 12 experiments were able to achieve a WUE greater than 11 kg/ha.mm^{-1}. The average WUE was 8.6 kg/ha.mm^{-1} where no N was applied, increasing to an average 11.1 kg/ha.mm^{-1} where the highest N rate was applied.

The data, combined with the knowledge of local N inputs and soil N reserves, suggests that WUE outcomes for canola could be improved by supplying the crop with more N. This can be done through the application of fertiliser N, or more sustainably through the use of legumes to enhance soil N.

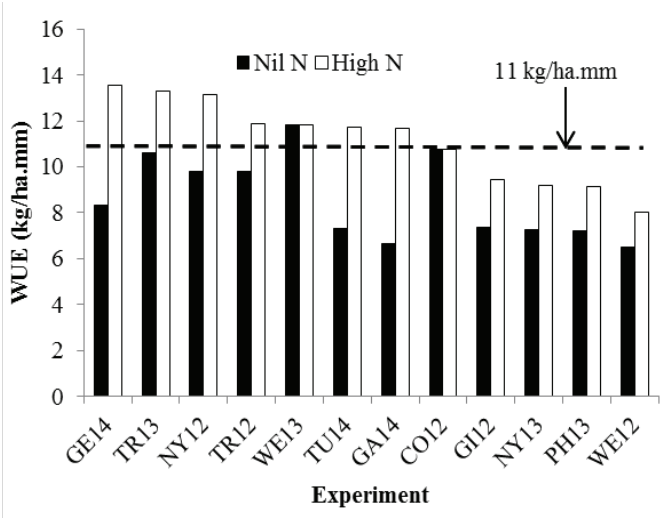

Figure 3: Water use efficiency (WUE) of nil N and highest N treatments in 12 canola nitrogen experiments across southern and central NSW from 2012 to 2014. A benchmark WUE of 11kg ha.mm-1 is included.

Conclusion

Grain yield responded positively to applied N in 10 of 12 experiments conducted in central NSW from 2012 to 2014. The application of N at any level did not reduce grain yield in any experiment. Although 'haying-off' has been widely reported in wheat experiments, there was no evidence of this occurring in canola in these experiments. Grain oil concentration was however negatively affected by increasing the rate of N applied in 9 of 12 experiments.

In the nil N treatments in these experiments, a WUE benchmark of 11 kg ha.mm^{-1} was achieved in only two experiments; however the application of N at the highest rate of each individual experiment resulted in eight experiments achieving the WUE benchmark of 11 kg/ha.mm^{-1}. With low soil N reserves and generally conservative N inputs for canola in these regions, it is likely that increasing the level of available N to commercial crops will increase WUE outcomes over a wide region.

Acknowledgements
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Determining the extent of declining pasture productivity with nitrogen fertiliser

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Declining productivity of sown pastures due to a reduction in plant available soil nitrogen has typically reduced grass and beef production by 50% since initial land development within the Brigalow bioregion of southern and central Queensland. As this decline continues, it's estimated it will cost the northern beef industry more than $17 billion over the next 30 years. To assist landholders determine the extent of declining pasture productivity on their own properties, and assess the magnitude of response if more nitrogen is made available, nitrogen fertiliser was applied to approximately 70 replicated and non-replicated sites across southern and central Queensland between 2012 and 2014. Nitrogen (N) fertiliser as Green Urea NV® (Incitec Fertilisers) was broadcast onto existing grass-pastures in the lead up to a forecast rainfall event in summer. A range of rates were applied, from 25 – 200 kg N/ha, and dry matter yields and protein levels were measured. At all sites the grass pasture responded to the added nitrogen, with the magnitude of response dependant on the amount of nitrogen applied. As the production from sown pastures continues to decline, options that improve nitrogen supply and address this decline will be required to improve beef production across the northern region.

Key words
Northern region, sown pastures, nitrogen immobilisation, dry matter production, fertiliser.

Introduction

Sown pastures in the Brigalow belt of southern and central Queensland are highly productive and support approximately 32% of the beef herd in northern Australia (ABS 2012; Peck et al. 2014). However dry-matter production and quality of these pastures declines after sowing, typically due to a reduction in plant available nitrogen supply through immobilisation of nitrogen (N) in plant residues and soil organic matter. This productivity decline has reduced grass and beef production by around 50% and as the process continues it's estimated that the cost to the northern beef industry will be more than $17 billion over the next 30 years (Peck et al. 2011).

A range of options can be implemented to improve nitrogen supply to these pastures. Focus group discussions with beef producers indicate high awareness of the decline in grass production over time however many are uncertain of the cause of this decline with climatic (low rainfall or a run of dry years) or grazing management being stated as the drivers (Peck *et al*. 2011). To address this uncertainty, we engaged beef producers to assess the extent of pasture productivity decline on their own properties, using nitrogen fertiliser. The intention was to demonstrate that soil nitrogen supply to the sown pasture is the primary limiting factor, not that fertiliser per se is the solution. Once a producer recognises soil nitrogen supply as the cause, the next step of identifying appropriate solutions to address the issue can be assessed as other options, such as legumes could also play a role.

Methods

The aim was for beef producers to assess the extent of pasture decline on their own properties, and while pasture sites were selected on a random basis, each was assessed by the owner as having declining productivity. Fertiliser as Green Urea NV® (Incitec Fertilisers) was used due to its high concentration (N 46; P 0; K 0) and high availability of nitrogen, and simplicity of application. Nitrogen release from this product is inhibited for up to 14 days, which generally provides sufficient time for rain to fall and incorporate the nitrogen, making it ideal for broadcasting into pastures. Beef producers who attended a workshop to understand and learn how to recognise and manage pasture productivity decline were provided with a

bag of fertiliser and a hand-held spinner to apply 100 kg N/ha in a strip 5 m X 20 m long. Most producers replicated this rate two or three times and also applied double and half rates, to broaden the investigation. The fertiliser was applied in summer and timed just prior to a forecast rainfall event to ensure incorporation. Cattle were excluded for 8 – 12 weeks following application to enable measurement of total pasture growth. All sites received sufficient rainfall (>50mm) during the summer growing season for the pasture to utilise the applied fertiliser. Just prior to the reintroduction of cattle to the paddock, or at the end of the growing season, quadrat cuts were taken within both the fertilised and adjacent unfertilised strips. This was done to assess pasture yield response and samples for whole-plant quality were also collected. Visual assessments of colour change, seed production along with height measurements were also taken, and these assessments were used to determine the extent of pasture decline at each site. Pasture samples were collected from each plot, dried at 80^0C and weighed to determine total standing grass dry-matter yield. Separate whole plant samples were collected and dried at 65^0C, ground to 2mm and analysed for total nitrogen. Results were then converted to protein by multiplying by 6.25.

Results and discussion

Response of sown pastures to nitrogen fertiliser

Applying nitrogen increased grass yield at all sites, the magnitude of which was dependant on the amount of nitrogen applied. At the higher nitrogen rates (100 kg N/ha and 200 kg N/ha), dry matter grass yield was around double that of unfertilised grass. This demonstrates declining sown pastures in central and southern Queensland have a large capacity to utilise extra nitrogen supply and produce higher pasture yield. Grass protein levels also increased, but only up to the 100 kg N/ha rate, beyond which protein levels stabilised (Figure 1).

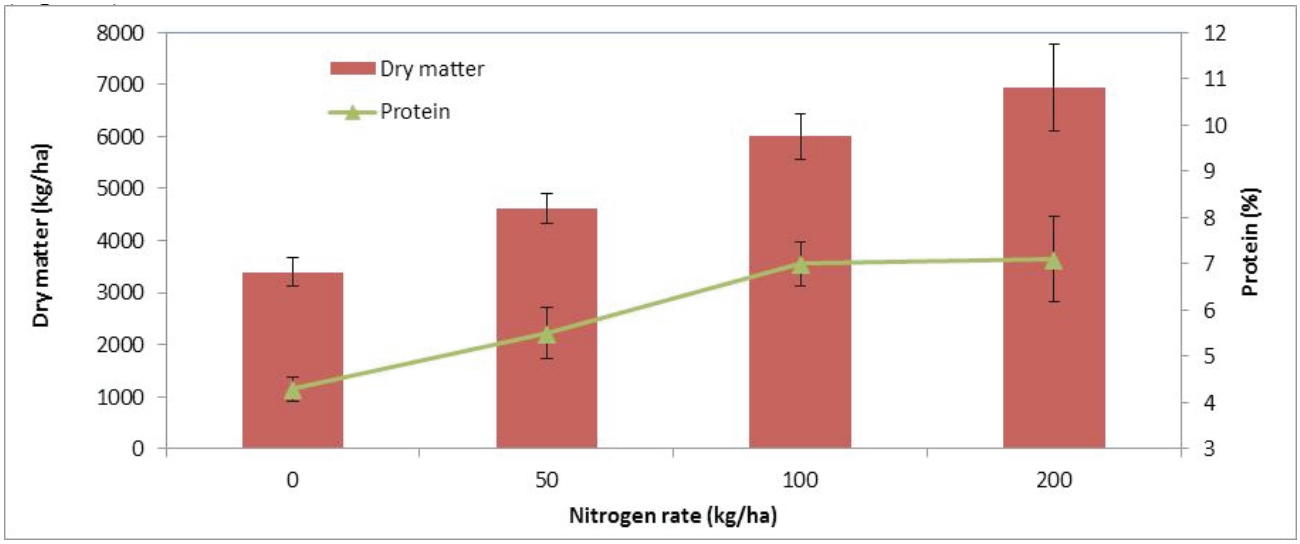

Figure 1. Average dry matter and protein responses of fertilised sown pastures. Error bars show standard error.

The capacity of the pasture to respond to nitrogen fertiliser changed as fertiliser rates increased. Dry matter response (kg DM / kg N applied) was lower at the 100 – 200kg N/ha fertiliser increment compared to the response at the 0 – 50kg N/ha and 50 – 100 kg N/ha increments (Figure 2). At the 0 - 50 kg N/ha fertiliser rate increment, 25 kg of extra dry matter per hectare was produced for every kg of nitrogen applied. The response was similar at the next increment (50 -100kgN/ha) with 28 kg of extra dry matter produced for every kg of nitrogen applied. The response rate decreased to 9 kg of extra dry matter at the 100 – 200kg N/ha fertiliser rate increment, indicating lower dry matter response efficiency at N rates above 100kg/ha. The response rates recorded in this study are similar to previous research in central Queensland on a buffel grass pasture, where a response of about 30kg extra dry matter of grass per kg nitrogen applied up to 120kg N/ha was measured (Graham et al. 1981). It's anticipated the response rate would increase as pastures decline further over time, based on other pasture growth factors remaining the same.

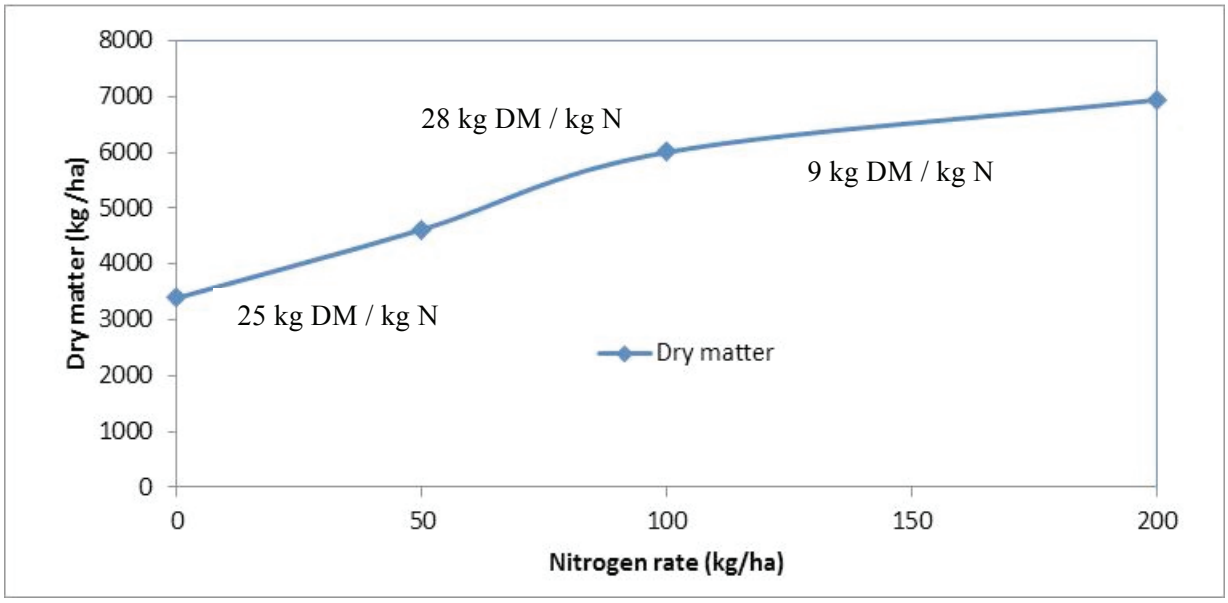

Figure 2. Average incremental response rate of sown pastures to increasing rates of nitrogen fertiliser.

While cattle stocking rate and live weight gain were not investigated in this study, it is assumed that fertilised pastures with higher grass production and protein could be utilised at higher stocking rates, and that animal growth would also be increased. The economics of fertilising sown pastures in southern and central Queensland is reported in another paper at this conference (Lawrence *et al*. 2015). This paper concludes that when 100 kg N/ha of fertiliser is applied, average gross margins in the year of application were calculated to increase by 121 - 217% when dry matter yield responses of 40 kg DM/kg N (i.e. an additional 4000kg/ha) and an additional liveweight gain of 0.2 kg/AE/Day (i.e. an extra 70 kg AE/year) can be achieved.

Extent and impact of pasture decline

An aim of this study was to demonstrate that soil nitrogen supply to the sown pasture is predominately the cause of declining pasture production, and not other factors such as rainfall. Before measurements at each site were undertaken, an assessment of pasture decline was conducted and sites were grouped into either 'moderate' or 'severe' pasture decline. A larger proportion of sites were assessed as having 'severe' pasture decline, and these pastures had lower dry matter yields (Table 1). This indicates productivity of most pastures across these districts has significantly declined, implying impacts to regional communities and the beef industry are high. The average pasture production from the unfertilised sites with 'moderate' pasture decline was almost 30% higher than the production from sites with 'severe' pasture decline. Combined with higher whole plant protein levels, sites with moderate pasture decline provide significantly higher beef productivity potential. This demonstrates the importance of determining the extent of decline and assessing options to reverse this trend before pastures reach a severe state.

Table 1. Dry matter yield and protein of pastures with either moderate or severe decline

Extent of pasture decline	Dry matter yield (kg/ha)	Whole plant protein (%)	Total number of sites measured
Moderate	4191	4.9	6
Severe	3229	4.2	35

The same nitrogen fertiliser rates produced comparable grass yields regardless of the extent of pasture decline, with higher variability occurring at the 200kg N/ha fertiliser rate for both dry matter and whole plant protein (Figure 3). This high variability maybe due to the low number of sites where this rate was applied, the lack of rainfall to enable the pasture to fully utilise this amount, or another limiting nutrient or environmental factors at one or more sites. Practically, this highlights the riskiness of applying such rates of nitrogen fertiliser in these districts, and that land managers need to assess small areas before such rates are applied across whole paddocks or properties.

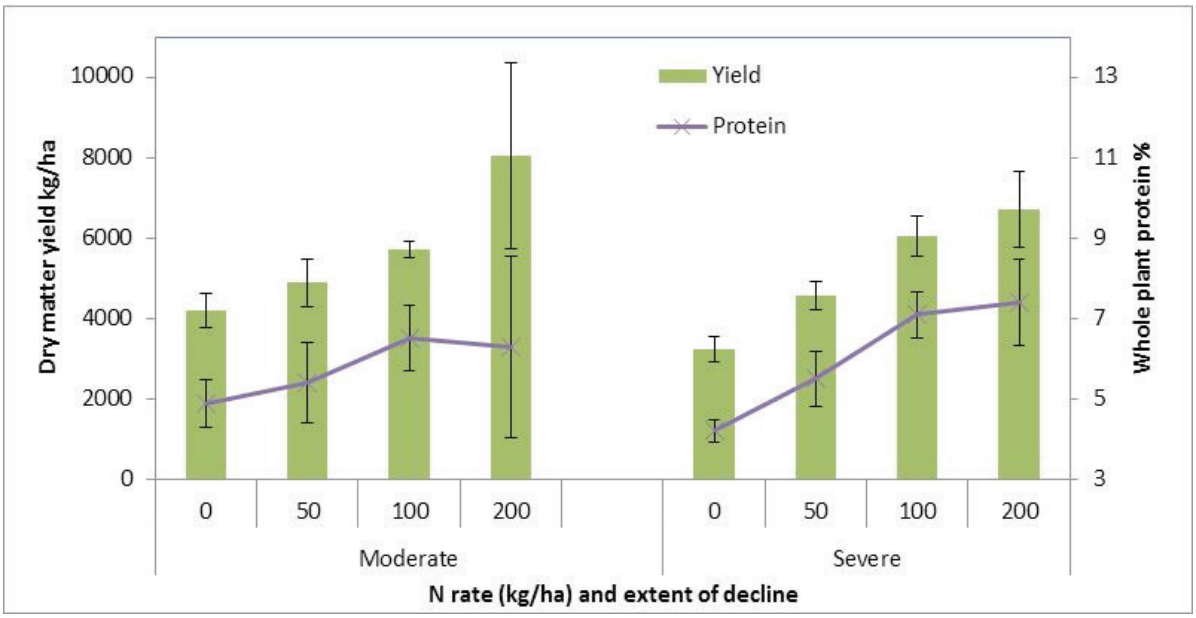

Figure 3. Average response to fertiliser in pastures with moderate and severe decline. Error bars show SE.

Conclusion

Sown pastures in the Brigalow belt of southern and central Queensland are highly productive however dry-matter production and quality of these pastures declines after sowing, typically due to a reduction of plant available soil nitrogen over time. Across the sites measured, larger proportions were assessed as having 'severe' pasture decline. This indicates the productivity of most pastures across these districts has significantly declined, implying impacts to regional communities and the beef industry are high.

Applying nitrogen fertiliser increased grass dry matter at all sites, the magnitude of which was dependant on the amount of nitrogen applied. At the higher nitrogen rates of 100 and 200 kg N/ha, dry matter yield was around double of unfertilised grass, demonstrating sown pastures with declining productivity have a large capacity to utilise extra nitrogen supply and produce more dry matter yield. Grass quality (protein) also increased, but this response was not as consistent as grass dry matter yield.

As the production from sown pastures continues to decline, beef producers need to assess the range of options and choose the one(s) that best suit their enterprise. The only long term solution to address declining pasture productivity would appear to lie in improving nitrogen supply through fertiliser use or integration of perennial legume species adapted to the landscape.

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‘Topping up’ wheat with foliar P: getting the right combination of P formulation and adjuvant

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Abstract
We are investigating whether it is possible to tactically top up phosphorus (P) supply with tactical foliar applications in seasons of higher yield potential, and as a result reduce the amount of fertiliser applied at sowing time. To test whether the form of adjuvant could affect the efficacy of foliar P applications, we evaluated the effects of 7 P formulations (laboratory reagents and commercial products) in combination with 3 adjuvants (LI700®, Hasten® and Spreadwet 1000®) on wheat growth, P uptake and P translocation in a pot experiment. Plants were grown in a highly P responsive soil with basal nutrients added before sowing. Foliar fertilisers labelled with ^{33}P were applied at flag leaf visible growth stage (GS37) as 2 µL drops, with an application rate equivalent to 2 kg P/ha in 100 L/ha total volume. The commercial products PeKacid® and Pick 15-42®, and laboratory reagents sodium and ammonium phosphate in combination with different adjuvants showed increases in plant biomass at harvest (GS 68) compared to the nil foliar control. The effects of adjuvants on P uptake and the interaction with P formulation will be discussed.

Key words
Foliar uptake, phosphorus, wheat

Introduction
For soils with a phosphorus (P) balance in the maintenance phase (Weaver and Wong, 2011), the fertiliser requirement is often marginal and dependent on in-season rainfall (McBeath et al., 2012). In Mediterranean systems like southern Australia most P fertiliser is applied at sowing, and does not allow the subsequent climatic conditions to be accounted for. With increasing costs of fertiliser P, this fertiliser input represents a large capital investment that could potentially be managed more effectively. We have been investigating whether an in-season P top-up by foliar application during seasons of higher yield potential is a possible management strategy that can also reduce starter P inputs as initially proposed and discussed in Noack et al. (2011).

In a previous study, we measured a 25% grain yield response of wheat to foliar P as phosphoric acid in the growth room in one of two soils evaluated (McBeath et al., 2011). Further work focussed on the use of phosphoric acid as the P source due to this initial yield response and availability of the product to farmers. However, a consistent yield response to phosphoric acid has been elusive. This is despite the foliar uptake of P from phosphoric acid being high (Peirce et al., 2014a) compared to ammonium phosphate (Fernández et al., 2014). In addition to the form of P, the inclusion of adjuvants, which are used to increase the effectiveness of foliar uptake through increased retention and penetration of the leaf surface, is necessary for wheat due to the hydrophobic nature of the leaves (Peirce et al. 2014b). Although the choice of adjuvant was not important in combination with phosphoric acid (Peirce et al. 2014b), it is not known whether interactions may occur between adjuvants and other forms of P to render them more or less effective. To investigate whether a different source of P may be more effective at increasing wheat biomass response and foliar P uptake and translocation, we evaluated 7 different P sources (commercial and laboratory grade) in combination with 3 commercial adjuvants.

Methods
Plant growth conditions
Plants were grown in 1.5 kg of soil in pots with a diameter of 10cm and depth of 17cm that were not free-draining. The soil, collected near Black Point, South Australia was classified as P responsive (Colwell-P 2 mg/kg, PBI 75 and DGT-P 3 µg/L) (McBeath et al., 2007)).

Before sowing, the soil moisture was increased to 22.5% (5% w/w) of field capacity (FC) with basal nutrients

mixed through the soil at mg/kg rates equivalent to those outlined in Peirce et al. (2014a), except for P which was added as H_3PO_4 at a rate of 4.8 mg P/pot (equivalent to 6 kg P/ha) to obtain a marginal P status in the soil, and allowed to equilibrate for a week. Additional nitrogen (25 mg/pot) was also applied to the soil surface and watered in at 15 and 27 days after sowing (DAS). Set up and growing conditions are outlined in Peirce et al. (2014a) but briefly, two plants/pot were grown in soil maintained at 80% FC in a controlled environment room (20 °C/15 °C day/night cycle of 12 h each) with the position of pots randomised every few days.

Foliar application

We evaluated the effectiveness of a range of formulations, both commercial and laboratory-grade reagents, in combination with three different adjuvants (Hasten®, Spreadwet 1000® and LI700®) (Table 1) on above-ground biomass, total and foliar P uptake and foliar P translocation. The three adjuvants belong to different classes (an esterified and emulsified oil, an alcohol alkoxylate surfactant and a mixture of soyal phospholipids and propionic acid, respectively) and were used to test whether the form of adjuvant influences the uptake and translocation of foliar-applied P. The experimental set-up consisted of 12 absolute controls (no foliar P) with 4 replicates of each of the 21 treatments (P source x adjuvant) to give a total of 96 pots.

Table 1. Phosphorus formulations evaluated in the growth room in combination with 3 different adjuvants (Hasten®, Spreadwet 1000® and LI700®).

P source	N : P : K (w/w %)	pH of applied fertiliser formulation
*Phosphoric acid	0 : 26.9 : 0	1.4
*PeKacid®	0 : 26.5 : 16.7	2.2
#Ammonium phosphate (MAP)	12.2 : 27.0 : 0	4.3
*Maxi-Phos 16 Neutral®	7.8 : 12.5 : 0	4.3
#Potassium Phosphate	0 : 22.8 : 28.7	4.4
#Sodium Phosphate	0 : 22.5 : 0	6.5
*Pick 15-42®	0 : 9.4 : 26.3	8.7

*Commercially available fertiliser #Analytical grade reagent

Foliar fertilisers were labelled with ^{33}P and applied 34 DAS at flag leaf visible (GS37, (Zadoks et al. 1974)) as 2 µl drops at a rate equivalent to 2 kg P/ha with N and K added by the foliar fertilisers balanced in the soil of all treatments at sowing. At anthesis (GS 68), plants were harvested and the treated leaves, heads and tillers were separated from the rest of the plant. All plant parts were washed as described in Fernández et al. (2014) to remove unabsorbed foliar fertiliser and all plant parts were analysed for P and ^{33}P contents. Analysis of variance (ANOVA) was undertaken using Genstat® V.15 statistical package. Least significant difference between treatments was determined at the 5% significance level using Fisher's protected l.s.d.

Results and Discussion

Selected foliar treatments resulted in a significant ($p \leq 0.05$) increase in above-ground plant biomass compared to the control when harvested at the end of anthesis (Table 2). Five foliar treatments (MAP with Hasten®, sodium phosphate with LI700®, and Pick 15-42® with all three adjuvants) had greater head biomass compared to the control. Additionally, Pick 15-42® with Spreadwet 1000® had higher (45%) total biomass than the control and were on average the largest plants out of all the treatments. A further two foliar treatments (PeKacid® with Spreadwet 1000® and sodium phosphate with Hasten®) resulted in a total biomass greater than the control. There were no treatments with significantly less total biomass than the control however Maxi-Phos 16 Neutral® with LI700® had lower biomass for other plant parts excluding heads.

Foliar uptake of all commercial products was high (except for potassium phosphate), in most cases greater than 90% of what was applied (data not shown, manuscript in preparation) which showed that at a rate equivalent to 2 kg P/ha, the P in the foliar products was able to cross the cuticular barrier irrespective of the formulation pH. The translocation of ^{33}P differed between products, with low translocation for some products (in particular phosphoric acid) but larger for all products that generated an increase in plant biomass (Table

2). The small proportion of phosphoric acid that was translocated is consistent with our previous work at similar foliar P rates (Peirce et al., 2014a) and is likely to explain the lack of biomass response for this product.

Table 2. Above-ground dry weight (g) of wheat plants and both foliar and total P content of heads (mg) at harvest

		Heads	Other plant biomass	Total	P content from foliar applied in heads	Total P content in heads
Control (no foliar)		0.83	1.78	2.60		1.72
Phosphoric Acid	Hasten	0.83	1.63	2.46	0.25	2.21 *
	LI700	0.80	1.63	2.43	0.24	2.01
	Spreadwet	0.66	1.27	1.93	0.32	1.76
PeKacid®	Hasten	0.99	2.09	3.07	0.53	2.30 *
	LI700	0.97	2.02	2.99	0.62	2.31 *
	Spreadwet	0.97	2.34	3.31 *	0.51	2.20 *
Ammonium Phosphate	Hasten	1.04 *	2.13	3.17	0.46	2.15
	LI700	0.91	1.72	2.63	0.44	2.25 *
	Spreadwet	0.83	1.67	2.50	0.39	1.82
Maxi-Phos 16 Neutral®	Hasten	0.99	1.78	2.77	0.65	2.05
	LI700	0.82	1.17 *	1.99	0.50	1.75
	Spreadwet	0.84	1.60	2.44	0.41	1.93
Potassium Phosphate	Hasten	0.86	1.95	2.80	0.08	1.88
	LI700	0.98	2.06	3.04	0.13	2.07
	Spreadwet	0.98	2.13	3.12	0.53	2.21 *
Sodium Phosphate	Hasten	0.95	2.60 *	3.55 *	0.49	2.17 *
	LI700	1.08 *	2.14	3.22	0.72	2.31 *
	Spreadwet	0.87	1.98	2.85	0.50	2.01
Pick 15-42®	Hasten	1.03 *	1.94	2.97	0.50	2.15
	LI700	1.08 *	1.65	2.73	0.73	2.21 *
	Spreadwet	1.13 *	2.63 *	3.76 *	0.60	2.18 *
l.s.d ($p \leq 0.05$)		*0.18*	*0.57*	*0.70*	*0.12*	*0.44*

Treatments annotated with * are significantly different to the control.

For a foliar application to be effective, once it is absorbed by the leaf, it must be able to move to the growing plant parts and be utilised for growth. Phosphorus is a nutrient that has been shown to be very effectively translocated from senescing plant parts to the grain when grown through to maturity (Batten et al., 1986). In this study we did not grow the plants through to maturity but harvested during anthesis when the expected sinks for foliar translocation, given the timing of application, are the flag leaf, head and tillers. For all foliar treatments, translocation occurred to all three of these sinks with the majority of foliar P translocating to the head even at this earlier growth stage. The foliar treatments which produced a positive head biomass response generally had both higher total and foliar P contents in the head (Table 2) as also noted by McBeath et al. (2011), although not all treatments with high total P contents produced a biomass response.

As expected from previous work (Peirce et al., 2014b), there were no differences in biomass, P uptake or P translocation for phosphoric acid in combination with the three different adjuvants. However, for other products differences were detected but only certain combinations increased biomass compared to the control (Table 2). This indicates that there are interactions that may occur between products and adjuvants to reduce the efficacy of a foliar fertiliser however predicting these interactions and subsequent outcomes before application is not yet possible as discussed by (Fernández and Eichert, 2009).

This experiment was conducted under controlled conditions as environmental factors including light intensity, temperature and humidity are known to influence the response of plants to foliar fertilization (Fernández and Eichert, 2009). Given we have been able to obtain positive biomass responses to foliar P

applications under these conditions, our next step is to test whether a foliar top-up application is a feasible management strategy under field conditions in soils with documented P responses.

Conclusions

The lack of response we have previously encountered with phosphoric acid is likely due to the inability of the plant to effectively translocate the absorbed P to growing plant parts. Conversely, a number of other foliar P products (PeKacid®, ammonium phosphate, sodium phosphate and Pick 15-42®) were effective at both absorbing and translocating foliar P when applied at growth stage flag leaf visible which resulted in an increase in plant biomass compared to the control treatment.

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Production interactions between combinations of 4 perennial legumes and 5 perennial grasses, grown under high input management with and without applications of nitrogen

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Abstract
The value of legumes in high input pastures has come into question in recent years. High sowing rates of grasses (> 20 kg/ha) and the regular use of nitrogen fertilisers are contributing factors to the declining composition of legumes in pastures. However, legumes can be an important component of a mixed pasture sward, through their ability to fix atmospheric nitrogen and their high nutritive value. This study evaluated the dry matter (DM) contribution of legumes to irrigated mixed swards receiving either a nil nitrogen or a 40kg N/ha nitrogen treatment following each defoliation event. The experiment was sown with 29 pasture treatments consisting of mixed swards and monocultures of 5 grass species (perennial ryegrass cv. Base, tall fescue *Festuca arundinacea* cv. Quantum II MaxP, coloured brome *Bromus coloratus* cv. Exceltas, cocksfoot *Dactylis glomerata* cv. Megatas and phalaris *Phalaris* hybrid cv. Advanced AT) and 4 legume species (white clover cv. Bounty, red clover *Trifolium pratense* cv. Rubitas, strawberry clover *Trifolium fragiferum* cv. Palestine and Caucasian clover *Trifolium ambiguum* cv. Kuratas). The clover contribution (%) to production increased significantly ($P<0.05$) in nil-nitrogen treatments compared with pasture mixes receiving nitrogen. The application of high rates of N fertilisers can inhibit significant contributions of legumes to overall production. White clover proved to be well adapted and the results of this study suggest it would difficult to justify the sole use of any alternative species tested.

Key words
Alternative pasture species, DM yield, perennial legumes, pasture composition, clover

Introduction
The majority of intensively managed pastures are characterised by grass dominant pastures requiring large inputs of nitrogen fertilisers to reach their potential productivity. However, legumes are promoted for inclusion in pastures because of their ability to fix nitrogen and improve nutritive value. The optimal proportion of legume in pastures is often quoted at around 30%. Recent studies by Suter *et. al*. (2015) suggested that total nitrogen yield in mixed pastures increases with increased proportion of legumes up to one-third. However, McKenzie *et al*. (2003a) suggested that the amount of N fixation from white clover in mixed perennial ryegrass/white clover pastures was low and insufficient to maximise dry matter production and that strategic applications of inorganic N can assist maximise production. Further, the application of N fertilisers can result in a decrease in N fixation from legumes (Ledgard and Steele, 1992). Hence, the heavy use of synthetic nitrogen applications in pastures has brought into question the role of legumes in high input pastures. Although the feed nutritive value of forage is increased by incorporating legumes into pastures, there are other methods of increasing overall diet nutritive value such as supplementary feeding of grain in the dairy industry which may be a more efficient means of achieving this. The biggest challenge is retaining or promoting legumes in mixed swards without a penalty in overall dry matter (DM) yield. This study evaluated the persistence and contribution in terms of DM of legumes in a range of alternative mixed swards under high nitrogen and nil nitrogen inputs.

Methods
The experiment was established in 2014 at Cressy (41° 43'S, 147° 03'E) in Northern Tasmania where the mean annual rainfall is 628 mm and the elevation 147 m. The soil is a brown chromosol, and can be described as duplex with a heavy clay subsoil. The trial was sown in April 2014 with an Ojyard cone

seeder into a shallow cultivated seed bed, prepared over 12 months from a previously degraded pasture. The experiment was a randomised complete block design with four replicates. Pasture cultivars were sown as both monocultures and in mixed swards, using all the grass/clover combinations. Sowing rate for each cultivar was dependant on seed size and if sown as a monoculture or in a mix (Table 1). Growing season rainfall (November 2014 – April 2015) was 152.5 mm plus an additional 665 mm of irrigation applied to make the study fully irrigated. Plots received either nitrogen applied at 40 kg N/ha, or nil nitrogen following each harvest event. Maintenance levels of phosphorus and potassium were applied at 42 kg P/ha and 169 kg K/ha respectively. Weeds and pests were controlled as required, although in some plots volunteer grass, legume and broadleaf weeds became difficult to manage as a result of slow or poor establishment of the sown species.

Plots were cut twice during establishment in early spring, prior to dry matter evaluation at 6 harvest dates between November 2014 and April 2015. Dry matter (DM) yield was assessed at six defoliation events between November 2014 and April 2015. Defoliation interval was between 26 and 34 days depending on growth rates. Dry matter (DM) yield was assessed across all pasture treatment plots by quadrat cuts (2 per plot) when the perennial ryegrass plots had reached the three leaf regrowth stage. Plants were defoliated to 5mm using hand shears and following collection the residual plot area was mown to 5mm and the dry matter removed. Pasture samples were botanically separated into the individual cultivars planted, with weed and non-sown species removed. Samples were oven dried at 56 °C for 48 hours to determine DM yield. The yield data were analysed assuming a split plot design with the whole plot in a randomised complete block design using Proc Mixed in SAS v 9.3. Since the data from each plot were autoregressively correlated a repeated measures framework was used. After examining quantile-quantile plots of residuals the data an arc-sine square root transformation was selected. Predicted means are shown on the transformed scale.

Table 1: Sowing rates (kg/ha) of pasture cultivars in monoculture (mono) and mixed swards

Grasses	**Mono**	**Mixed**	***Legumes***	**Mono**	**Mixed**
Perennial ryegrass *cv. Base*	15	12	White clover *cv. Bounty*	6	3
Coloured brome *cv. Exceltas*	20	12	Red clover *cv. Rubitas*	6	4
Cocksfoot *cv. Megatas*	5	3	Strawberry clover *cv. Palestine*	6	3
Tall fescue *cv. Quantum II MaxP*	12	10	Caucasian clover *cv. Kuratas*	6	4
Phalaris *cv. Advanced AT*	5	3			

Results

There was a significant ($P<0.05$) nitrogen application effect on the dry matter production of all pasture treatments, with the exception of phalaris/white clover, phalaris/red clover and clover monocultures. The application of nitrogen had a significant ($P<0.05$) effect in suppressing the clover % of DM yields in mixed swards, with the exception of the coloured brome/Caucasian clover mixed sward. There was also a significant ($P<0.05$) harvest time effect on clover % of DM yields, except in perennial ryegrass/Caucasian clover, coloured brome/Caucasian clover and cocksfoot/Caucasian clover mixed swards. Significant ($P<0.05$) nitrogen*harvest time interactions were found in all mixed swards except perennial ryegrass/Caucasian clover and coloured brome/Caucasian clover. The contribution of all clovers to DM increased over time in both nil-nitrogen and nitrogen treated phalaris mixed swards (Figure 1).

Discussion

Overall production was higher in most pasture treatments receiving the nitrogen than the nil nitrogen. The non-significant effect in plots containing phalaris/white clover and phalaris red clover can be explained by the relatively low yields and growth habit of phalaris compared with other grasses, promoting the production of white and red clover. Further, the non-significant result in clover monocultures is due to their ability to fix their own nitrogen rather than rely on inorganic nitrogen being applied. The yields of Caucasian clover in all swards were significantly lower than other clovers. The April sowing time of this experiment is thought to have contributed to the relatively poor production of Caucasian clover in this instance, with spring sowing preferable for this relatively slower establishing species (Hall and Hurst, 2013). Further evaluation of Caucasian clover is required under are a more favourable sowing time as Caucasian clover has been shown to produce more N and more total dry matter in perennial ryegrass based mixed swards than white clover (Widdup *et al*. 2001).

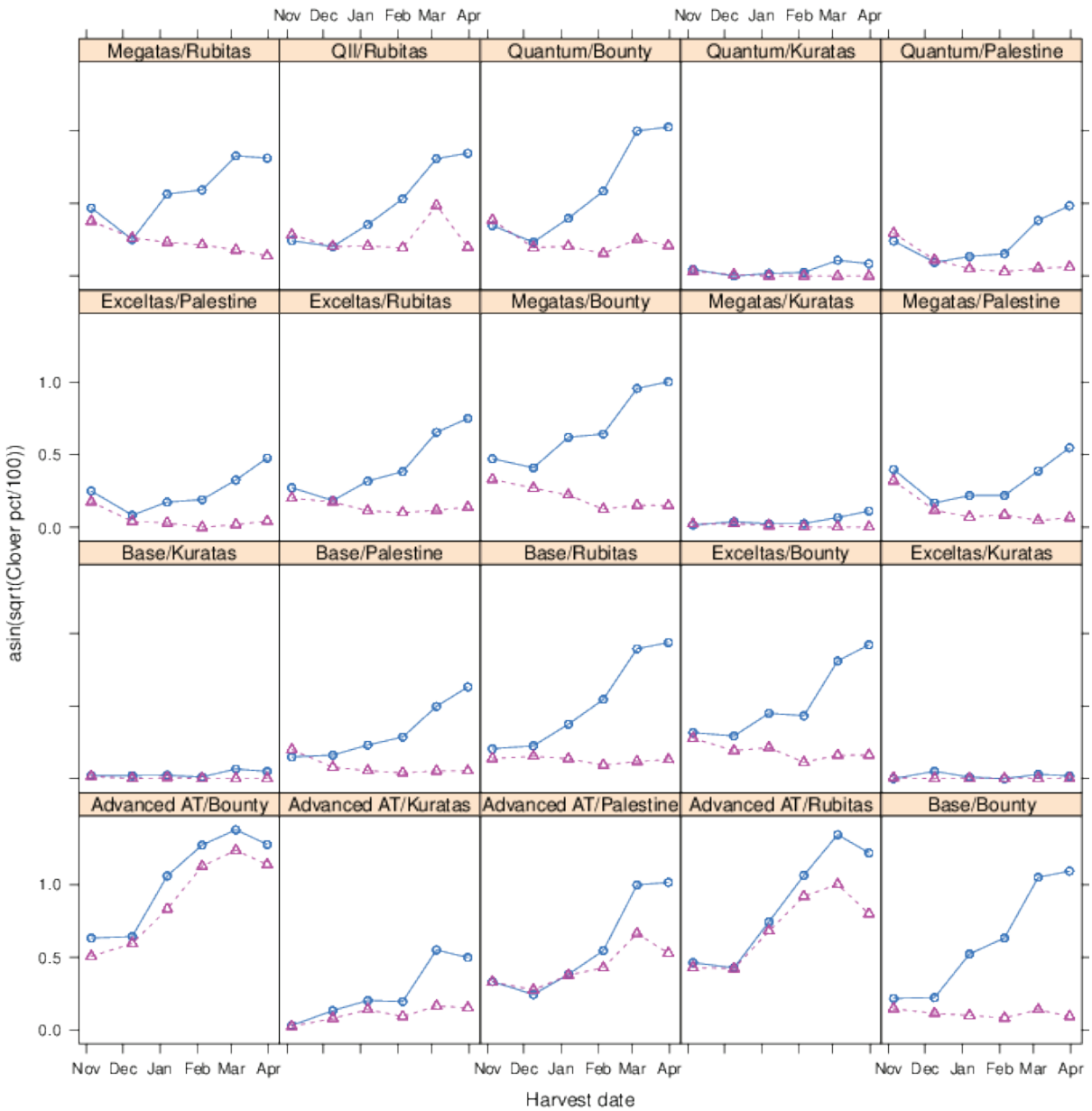

Figure 1: The contribution of dry matter (%) of clover in mixed pasture swards. Pasture treatments received either nil-nitrogen (blue circle) or 40 kg/N/ha (pink triangle) following each harvest. Shown are the predicted means of clover contribution (%) on the transformed scale. The SE for each harvest dates are as follows; 0.04, 0.03, 0.04, 0.04, 0.06 and 0.04.

The application of nitrogen following each harvest suppressed the clover contribution (%) to the dry matter production. Clover contribution (%) to production remained low over time in plots receiving nitrogen. In contrast, the clover contribution (%) to production increased significantly in plots receiving nil nitrogen, with the exception of mixed swards with Caucasian clover. The increase in clover may be explained by the depletion of available nitrogen at each harvest date with the removal of dry matter and no nutrient return disadvantaging the DM production of grasses. It was observed that legumes became quite dominant in nil-nitrogen swards by the last harvest.

The contribution of legumes in fixing nitrogen was evident in some nil-nitrogen plots. It was observed that grass plants appeared healthier in nil-nitrogen mixed swards containing white clover and red clover was far superior to grasses in mixed swards with low amounts of Caucasian clover. This observation would affirm that N fixation is positively correlated with legume DM yield (Widdup *et al*., 2001; Carlsson and Huss-Danell, 2003).

The observation that the clover contribution (%) to production increased in both nitrogen and nil-nitrogen phalaris plots over time is in contrast to plots based on perennial ryegrass, coloured brome and cocksfoot. The semi-erect growth habit and low level of summer dormancy (Culvenor, 2009) are likely to have promoted the growth of clovers; 1. Due to the reduced competition for light, the canopy was much more open; and 2. Lesser competition for nutrients. This observation provides a clue to how to maintain legumes in high input pastures. McKenzie *et al*. (2003b) showed that the composition of white clover in pastures can remain the same with increasing nitrogen applications, but the contribution to DM yields can be reduced. They cited that optimal grazing that maintains an open canopy is a possible reason for this.

The contribution (%) of the four legumes studied here to the production of mixed pastures receiving high rates of N fertilisers was low. White clover proved to be well adapted to the environment and the high input irrigation management used in this study and the results suggest it would difficult to justify the sole use of any alternative species tested. Efforts may be better placed in determining a grazing management system that promotes the growth and persistence of clovers. However, the urgency to develop such management systems may be reliant on the price of inorganic N fertiliser.

Conclusion

This study has shown that the application of high rates of N fertilisers will inhibit significant contributions of legumes to overall production. Further experiments using a range of nitrogen rates is required to find the correct rate for optimising legume composition. In addition, further work is required to evaluate the contribution of these legumes in improving feed quality, as DM production is just one factor in animal production.

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A bioeconomic framework for phosphorus deep-placement decisions

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Abstract
Research indicates potential yield benefits from replenishing phosphorus (P) in sub-surface layers (10-30cm) if soil tests indicate a deficiency; however, it was unknown if amelioration has economic merit. Deep-P placement is a longer-term decision due to initial application and P fertiliser (MAP) costs with potential benefits that can last for many seasons. However there are risks due to unknown future season types. The fundamental question of deep-P placement is "how much P and how often?" We developed a bio-economic framework and used a case study in the Goondiwindi region with a deep-soil Colwell-P of 5 mg/kg to demonstrate the risk and benefit of applying different amounts of MAP at depth for a "short-rotation" (3-years) and "long-rotation" (7-years). The results indicate: (a) the optimal MAP rate was 135 kg/ha and 270 kg/ha for the short- and long-rotations, respectively, resulting in real-annual returns of $43/ha/year and $76/ha/year; (b) the short-rotation risked a loss of -$14/ha/year compared to $6/ha/year for the long-rotation (worst case); and (c) due to the lower investment cost with the short-rotation, the expected return on investment was 142%, compared to 67% p.a. for the long-rotation. The payback period for both decisions was around 2-years. As with all risky decisions, the farmer will have to weigh up the benefits, risks and their financial situation. Economic results will change when biophysical or pricing parameters change. As our knowledge of deep-P responses improve they can be incorporated into this bio-economic framework.

Key words
Phosphorus, deep-P, long-term nutrient decision, economics, risk, framework

Introduction

Phosphorus (P) is an increasingly important nutrient for northern grains region (NGR) (Bell et al., 2012; Singh et al., 2005). Small amounts of P are needed during early crop growth, to establish yield potential through high grain number initiation. Thus starter P is applied at the time of planting. However, as the plant develops it needs increasingly larger amounts of P to establish a high tiller density (in cereals), and to promote vigorous root systems, increase plant biomass and ultimately fill grains (in all species). Historically this P has been available from native subsoil P reserves, but years of grain P removal has diminished subsoil P reserves. Starter P fertiliser meets the demands of young seedlings with very small root systems but doesn't meet the demands of well-established plants growing on subsoil moisture later in the season. During this time the plants need to access nutrients such as P where the moisture is, in the lower soil layers.

Economic nutrient decisions can broadly be categorised into short- and long-term decisions (**Table 1**). Application of P deeper in the soil will inevitably result in some moisture loss and soil disturbance, so deep-P applications need to be done well before planting to allow time for replenishment of the surface soil moisture and restoration of seed bed conditions. In addition, the cost of deep P application and the high application rate requires economic analysis for more than a single season. This is in contrast to starter P and N rate decisions that are based on crop requirement in the current season.

Table 1: Factors involved with short and long-term fertilizer decisions

Starter P and N Short-term decisions	Deep-P Long-term decisions
• Main benefit in current season • Unknown season type or yield but known starting moisture • Fixed N and P prices at application • Assume no other nutrient constraints	• Benefits for many seasons • Unknown future season types, soil water & yields • Unknown future P and N prices • Need to assume future decisions will provide sufficient starter P & N • Fixed P prices at time of the decision • Time value of money ($$$ in the ground vs bank)

When considering the outcomes of long-term decisions there are two fundamental economic considerations: risk and the time *value of money*. The further we look into the future the greater the uncertainty and therefore the risk. However, the longer we have to wait for a reward the lower its current value, and impact on our decision. The outcome in a 100 years is very risky but of little value, or impact, for many of us. Most long-term farm-level decisions are limited to 10-20 years in the future. Therefore a bio-economic framework is needed to obtain the optimal application rates and the associated risk for up to 10 crops.

Research method

We developed a framework using APSIM and Excel® for 12 regions within the Northern Grains Region (NGR). The optimal deep-P application rate is driven by both biophysical and economic components of cropping systems (**Figure 1**).

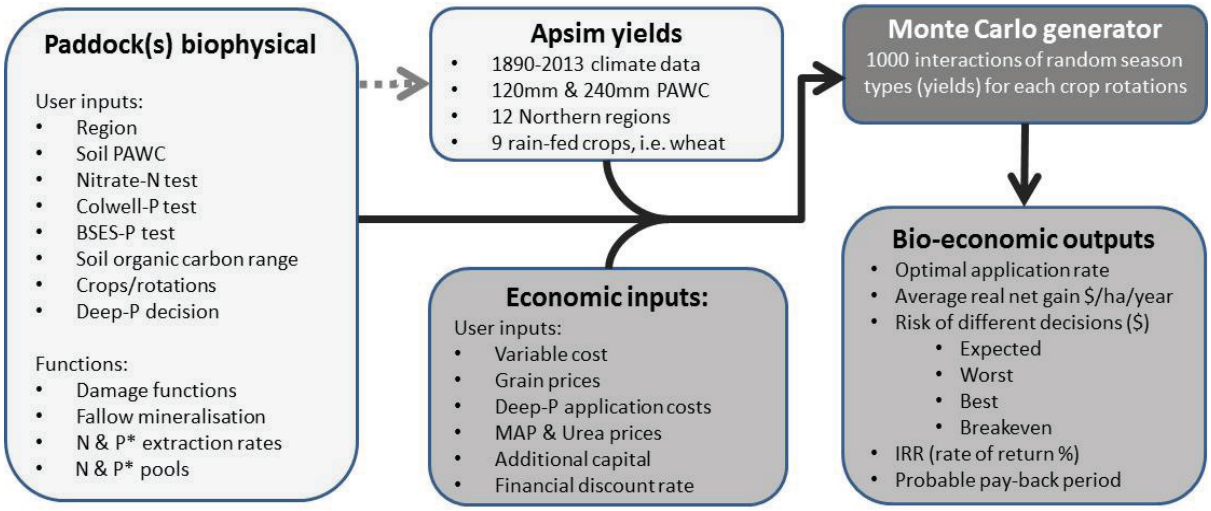

Figure 1: Schematic of the bio-economic framework of long-term decisions of deep-P placement using APSIM® and Excel®

Based on previous research (Bell et al., 2014), we have assumed that soil will be responsive to deeper-applied P when Colwell P is <10 mg/kg and BSES P is < 30 mg/kg in the 10-30cm layer, PBI <150, and any residual applied deep-P will remain available in the short term (~5 years). In this study we have assumed that 1 mg/kg Colwell P represents 1 kg plant-available P/ha in a 10cm layer and that all applied P enters the plant available pool. The 10-30cm soil test layer represents two soil bands 10cm thick (10-20 and 20-30 cm), therefore the amount of P in that layer is twice the soil test value.

There is little historic data in the NGR on responses to deep P for any crops – other than what we have generated in the last few years. Therefore we have used three basic season types, with characteristics that influence crop response to deep P, as suggested by Bell et al. (2014):

- Dry start – those years with little or no effective rainfall from planting until after tillering;
- No stress – no severe crop stress; and
- Late stress – those with enough rain to ensure good early growth, but serious finishing water deficits.

Case study

The case study is based on a paddock in the Goondiwindi region (Qld), producing sorghum (**S**), chickpea (**CP**) and wheat (**W**) on soil with a plant available water capacity (PAWC) of 180 mm, starting nitrate-N of 50 kg N/ha, soil organic carbon of 0.9%, Colwell-P soil test in the 10-30 cm of 5 mg/kg, BSES-P of 15 mg/kg and PBI of 100, meaning the soil is very likely to be P responsive. We compared the benefits and risks of applying varying rates of MAP at depth for a short-rotation of **S CP – W – W** to a long-rotation of **S CP – W – W – – S CP – W – W**. Goondiwindi climatic records (1890-2013) are used to estimate season types and to run APSIM. Deep-P placement was with a John Deere® 8400 tractor and planter attachment set at a soil-depth of 200-250 mm at a cost of $31.58/ha and MAP (P = 22%) was costed at $730/t. Additional assumptions are shown in (**Table 2**).

When dealing with long-term investments we need to consider the time value of money, which includes the opportunity cost of not investing elsewhere or financing and project risk. We do this by discounting future

cash flows into net present values (NPV). Assuming bank financing and climatic risk, the discount rate is 10% p.a. To compare long-term investments of different time horizons, we need to convert NPVs into annuities, i.e. the average annual net benefit ($/ha/year) over the project life. The investment horizon starts at the time of deep-P application just prior to planting. Another long-term investment measure is the internal rate of return (IRR), i.e return on investment over the project life. Any P depleted from or left in the soil at the end of the time horizon is ignored. This deep-P framework is to be used in a stepwise fashion through time and deep-P decisions re-evaluated based on changes to subsurface P reserves.

Table 2: Input criteria relating to P and N removed, the yield damage (discount) from P deficiency (from Bell et al. 2014) and crop-related costs and prices

	Removal of N & P from soil (kg/t grain)		Damage (discount) to crop when Colwell-P<10mg/kg (average of trial results)						Variable costs	Farm gate prices
			120mm PAWC			240mm PAWC				
Crop	P	Net N	Dry start	No stress	Late stress	Dry start	No stress	Late stress	$/ha	$/t
Chickpea DC	3.8	0	5%	10%	15%	30%	10%	25%	342	409
Sorghum LF	2.3	17	5%	15%	10%	10%	15%	25%	462	230
Wheat	2.6	23	5%	15%	10%	10%	15%	25%	319	257

Results

Optimal P fertiliser rate, returns and risk

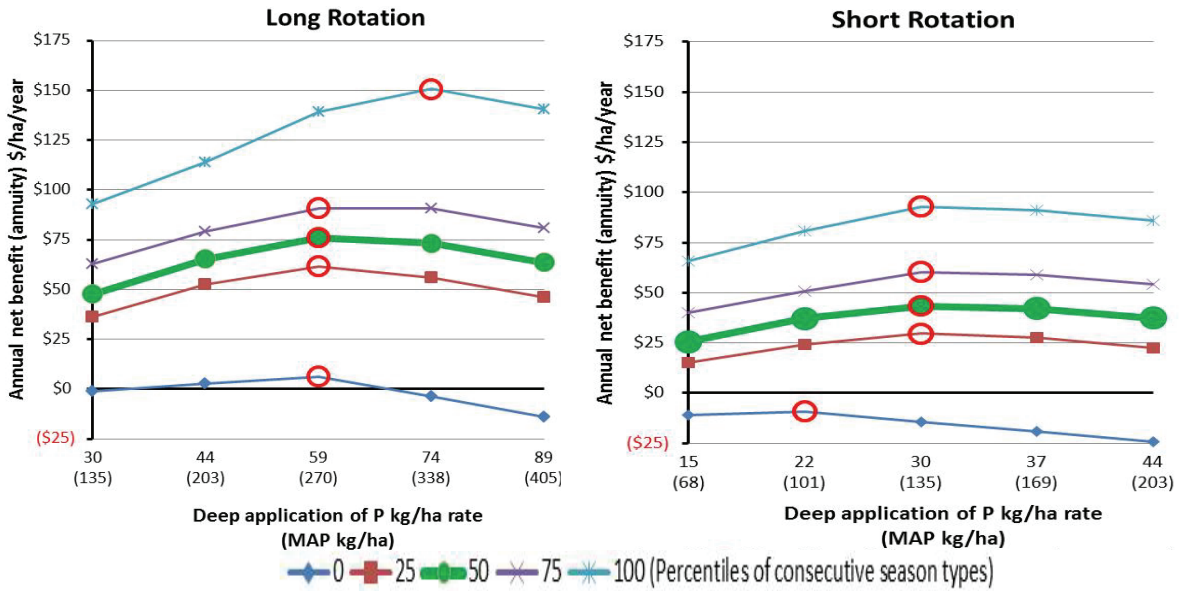

Figure 2: The real annual net benefit of deep-P (MAP) placement of a short and long rotations with respect to different seasonal outcomes: percentile = 0 is the worst-case scenario, 100 is the best case, and 50 is the expected outcome. The red circles indicate the optimal application rate for the given seasons.

Based on the expected (median or 50 percentile) outcomes, the optimal deep-P application rate for the short- and long-rotations are ~135 kg/ha and 270 kg/ha of MAP with an annual net benefit of $43/ha/year and $76/ha/year, respectively for this case study (Figure 2). Under the worst-case scenario (0 percentile), being a series of poor seasons, the optimal application rate for the long-rotation did not change but resulted in the annual net return of only $6/ha/year; however, for the short-rotation the optimal rate decreased to 101 kg/ha of MAP and resulted in -$9/ha/year. Under the best-case scenario (100 percentile), rain when you want it, the optimal application rate was 338 kg/ha of MAP for the long-rotation resulting in $150/ha/year, but this rate was excessive for all other seasons. Although not presented, there was 7% probability of not breaking even for the short-rotation; the long-rotation was almost certain to breakeven. The long-rotation had stochastic dominance and therefore always resulted in a higher annual net return.

The internal rates of return (IRR) for the short- and long-rotation were 142% and 67% p.a. respectively, which were both far greater than the opportunity cost of 10% (Figure 3a). Although the annual returns of

the long-rotation were higher under all situations, the expected (median) IRR was lower due to the higher initial financial investment. However, the risk (uncertainty) associated with the short-rotation was greater. Under the worst-case scenario it was possible to have an -18% IRR and there was a 5% chance of getting a negative IRR. The higher uncertainty of the short-rotation was also indicated by the high IRR under the best-case scenario of 750% compared to the long-rotation 224%. In summary, the IRR of the long-rotation was lower, but was less variable and was almost guaranteed to have a positive IRR. Although not shown, both the short- and long-rotation have about an 85% chance of getting >10% (the assumed opportunity cost). The expected payback period of both the short- and long-rotations was two-years (Figure 2). There was a greater probability of the short-rotation decision being paid back sooner due to the lower P rate and hence a low initial investment cost, but this was countered by a 1% chance of never receiving a payback.

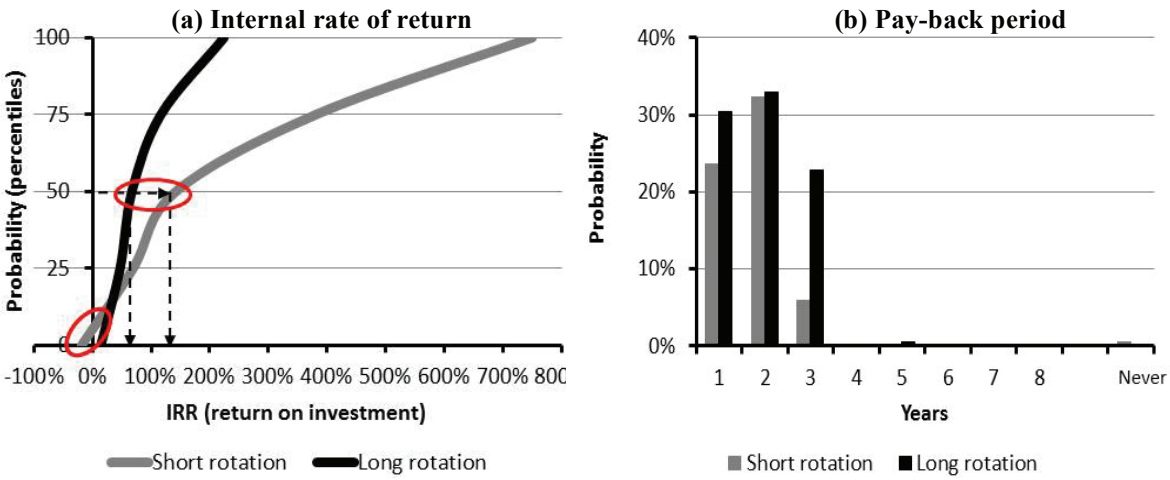

Figure 3: (a) The distribution of internal rates of return for the short- and long-rotation option: percentile = 0 is the worst-case scenario, 100 the best-case, and 50 the expected. (b) The frequency of which the initial investment is paid back in a particular year. "Never" indicates that it was never fully paid back.

Discussion

Deep-P decisions differ to most fertiliser decisions because they involve a single high application of fertiliser product that is aimed to supply financial benefits over a number of seasons for which future climatic conditions are unknown. Several technical and economic factors need to be included in the analysis. The decision to apply deep-P has the following considerations that this economic framework (calculator) can address: (i) Is deep P required?; (ii) What is the optimum deep-P rate to apply for a given time horizon?; (iii) How much P, how often and what is the risk?; and (iv) What is the internal rate of return and payback time?

The framework can be used to examine the cost/benefit trade-offs of deep-P decisions over time and the implications of expected prices, costs and crop rotation practices. Moreover this framework can also be used by farmers to communicate the potential returns and even the risk (worst-case scenarios) to financial institutions, when seeking additional finance. This case study of different application rates is only one example for which this framework could be used, and while the assumptions underlying P response in different seasonal types and the longevity of residual benefits of deep P are rudimentary, they can be updated and refined as further experimental evidence accumulates.

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NPK fertilisers as agents for the biofortification of trace elements in wheat

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Abstract
Millions of people across the globe suffer from malnourishment as a result of deficiencies to trace elements. This study addressed whether different combinations and concentrations of NPK fertilisers can assist in the biofortification of Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn) and Zinc (Zn) in wheat (*Triticum aestivum* cv Mace). In field and glasshouse trials, the uptake and accumulation of B, Cu, Fe, Mn and Zn differed when NPK fertilisers were applied in different combinations and rates. When N was applied in conjunction with P and K, grain B and Mn concentrations increased by 0.4 mg kg^{-1} (≈40%) and 5-22 mg kg^{-1} (up to 56%), respectively. Conversely, when N was applied in conjunction with P and K grain Cu and Zn concentrations decreased by 2-4 mg kg^{-1} (20-40%) and 10 mg kg^{-1} (16-28%) respectively relative to when N was supplied on its own. These observations highlight that management of NPK fertilisers and residual P and K concentrations in soil can assist in improving trace element uptake in wheat, however, further research is required to fully ascertain whether this process could be used at a commercial scale and if the trends will apply in other cropping regions and other crops both within Australia and across the globe.

Key words
Boron; Copper; Iron; Manganese; Zinc; uptake; accumulation; trace element deficiencies

Introduction
Deficiencies of essential trace elements (e.g. Se, Zn, Fe, B, Mn, Cu) affect the health of millions of people globally (Rengel *et al*., 1999). Trace element deficiencies in humans can be alleviated through the process of 'biofortification' whereby cereals and other food staples are fertilised with trace elements which are translocated to the grain and then to humans (Cakmak, 2008). Research investigating trace element biofortification in crops has focused on improvements to breeding and the effectiveness of trace element fertilisers (Rengel *et al*., 1999; White and Broadley, 2005). Far less research has explored whether the supply of macro-nutrients (e.g. N, P, K) can influence trace element uptake and sequestration in cereals (Li *et al*., 2007). This is surprising given that interactions between nutrients and trace elements are ubiquitous (Fageria, 2001). Most research on the influence of nutrients on trace element uptake in crops has focused on N (Fageria, 2001). There has been limited consideration of how interactions between N, P and K fertilisers influence trace element uptake. This is worthy of investigation, given that P and K are present in considerable concentrations in most cropping soils as a consequence of widespread fertiliser use during the second half of the 20th century (Neuhaus, 2012; Weaver and Wong, 2011). This research has two goals, (1) to establish if different combinations and concentrations of NPK fertilisers alter trace element uptake in wheat relative to N fertiliser alone; and (2) to determine if different residual P and K concentrations in soil alter relationships between N and trace elements in terms of uptake and sequestration in cereal grains.

Methods
Glasshouse trial
Triticum aestivum cv Mace was grown under four nutrient series - N only; N+P; N+K or N+P+K. N was applied as urea at 15, 45 and 135 mg N kg^{-1} in all nutrient series. The 'N only' series received no fertiliser P or K. The N+P series received 4, 12 and 36 mg P kg-1 as triple super phosphate (TSP) in conjunction with the N rates detailed above (i.e. 15N + 4P; 45N + 12P; 135N + 36P). The N+K series received 13, 38 and 113 mg K kg^{-1} as KCl in conjunction with N (i.e. 15N + 13K; 45N + 38K; 135N + 113K). The N+PK series received all N, P and K fertiliser regimes at all 3 levels described above (e.g. 15N + 4P + 13K). In addition, a reference treatment containing no added nutrients was used. Triplicate pots (n=3) were prepared for each treatment regime (n=13) in a randomised block design. Plants were grown in 1m PVC pots filled with 30cm of soil from the ex-DAFWA research station at Vasse (33.45^{o}S, 115.22oE) on top of yellow sand (30-100cm). The Vasse soil contained non-limiting concentrations of all trace elements as determined by DTPA extraction (Lindsay and Norvell, 1978) and $CaCl_2$ extraction (B only) followed by ICP-AES analysis (Rayment and Lyons, 2011). Concentrations of trace elements were thus consistent across all treatments and

represented indigenous trace element concentrations present in soil at seeding (i.e. no trace element fertilisers were applied) (Table 1). Plants were grown to maturity and trace element concentrations in the grain and shoots were determined using a HNO_3:HClO digestion (McQuaker *et al*., 1979a) followed by analysis using ICP-AES (McQuaker *et al*., 1979b).

Field trials

Wheat *cv* Mace was grown in three locations within Western Australia. Two trials were performed at the DAFWA field station in Wongan Hills (30.90oS, 116.71oE), one on a "high nutrient background" soil (1) and one on a "low nutrient background" soil (2). A third trial was performed at the UWA field station at Shenton Park (31.57oS, 115.48oE). Plants were grown under the same nutrient series as in the glasshouse trial. N was applied at 30, 60 or 90 kg N ha^{-1} as urea. The N only series received no fertiliser P or K. The N+P series received 8, 16 or 24 kg P ha^{-1} as TSP in conjunction with N (e.g. 30N + 8P). The N + K series received 25, 50 or 75 kg K ha^{-1} as KCl in conjunction with relevant N rates (e.g. 30N +25K). The N + P+K series received all N, P and K fertiliser regimes described above (e.g. 30N + 8P + 25K). A reference treatment containing no added N, P or K was also used. Triplicate plots (n=3) were prepared for treatment (n=17) in a randomised block design. Plot size was 2x10m at both Wongan Hills trials and 2x2m at Shenton Park. Mace was sown at 80 kg ha^{-1} in all trials. Concentrations of B, Cu, Fe, Mn and Zn were determined in soil and grain as per the glasshouse trial. Soil macronutrient and trace element concentrations across the three trials are described in Table 1.

Table 1. Indigenous soil nutrient and trace element concentrations at seeding in field trials.

Trace element/ nutrient	Critical con-centrations (mg kg^{-1})	Vasse soil glasshouse trial (mg kg^{-1} ± SE)	Shenton Park field trial (mg kg^{-1} ± SE)	Wongan Hills field trials (2) (mg kg^{-1} ± SE)	
				(1) 'high background nutrient'	(2) 'low background nutrient'
B	0.5	0.50 ± 0.02	0.16 ± 0.01	0.50 ± 0.01	0.48 ± 0.02
Cu	0.3-0.7	1.52 ± 0.02	2.5 ± 0.6	0.60 ± 0.04	0.5 ± 0.1
Fe	N/A	142.8 ± 11.4	10.6 ± 0.3	63 ± 5	40 ± 6
Mn	5	5.6 ± 0.1	0.8 ± 0.1	10 ± 2	2 ± 1
Zn	0.2-0.4	23.3 ± 1.5	1.0 ± 0.1	0.7 ± 0.1	0.6 ± 0.1
P	15	20 ± 1	45 ± 3	33 ± 5	25 ± 2
K	40	18 ± 3	39 ± 3	175 ± 21	58 ± 10
S	5	8 ± 1	2 ± 1	48 ± 9	10 ± 1

Results

Grain B (P=0.001), Cu (P=0.005), Fe (P<0.001), Mn (P<0.001) and Zn (P=0.011) concentrations were influenced by different fertiliser treatments under glasshouse conditions (Figs 1-4). Different NPK fertiliser combinations and rates also influenced trace element uptake and translocation in two of the three field trials. At Shenton Park grain Cu (P<0.001); Mn (P=0.009) and Zn (P <0.001) concentrations responded to different combinations of NPK application. On the lower nutrient Wongan Hills trial (2), grain B (P=0.003) and grain Fe (P=0.011) concentrations were influenced by different NPK regimes. On the Wongan Hills trial containing high residual K and S in the soil (1) there were no statistical differences in trace element concentrations when different NPK fertiliser combinations and rates were applied.

In both glasshouse and field conditions grain B concentrations increased by up to 0.4 mg kg^{-1} (22%) when N was applied in conjunction with P, particularly at high N concentrations (135 mg N kg^{-1} in pots and 60-90 kg N ha^{-1} in field) (Fig 1).

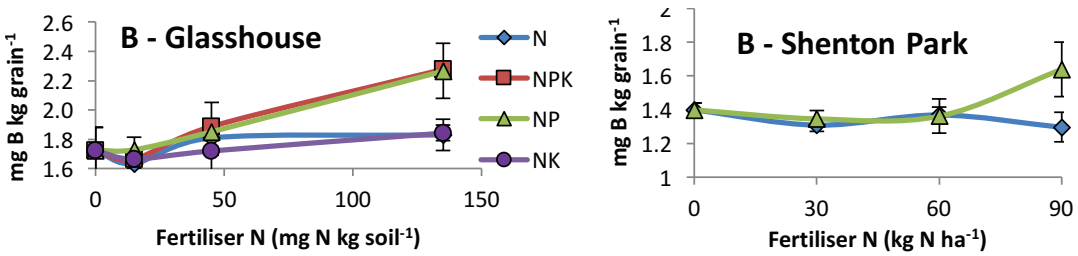

Figure 1. Grain B concentrations in Mace when grown under different NPK fertiliser regimes under glasshouse and at Shenton Park. Error bars represent standard errors of the mean (n=3)

Grain Cu concentrations conversely, decreased when N was added in conjunction with P and K (Fig 2), with losses in glasshouse trials between 2-4 mg kg^{-1} (~20-40%) and maximum losses in field trials of approximately 1 mg kg^{-1} (~30%) relative to when N was supplied alone (Fig 2).

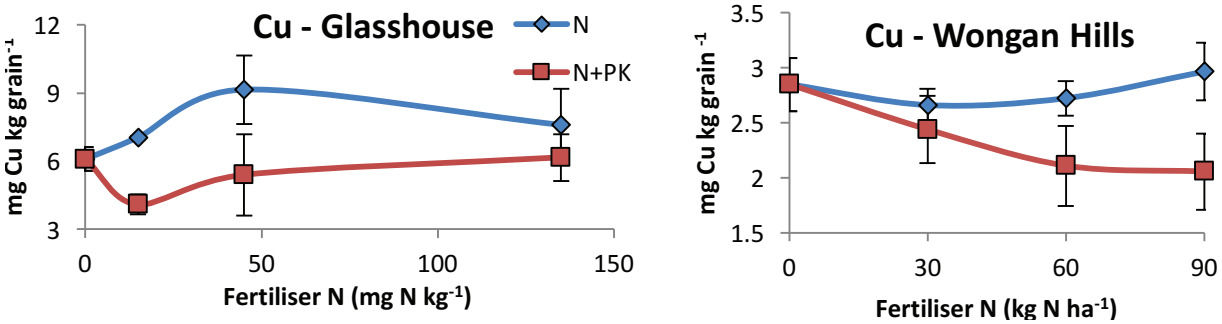

Figure 2. Grain Cu concentrations in Mace when grown under different NPK fertiliser regimes under glasshouse and field conditions. Data from field is from the Wongan Hills 'low nutrient' site. Error bars represent standard errors of the mean (n=3)

The addition of P reduced Fe uptake in the grain by 5-8 mg kg^{-1} (≈12-25%) at all three N concentrations used in the glasshouse, however, in the field this relationship was not evident (Data not shown).

In both glasshouse and field conditions, applications of P and K fertilisers individually and in combination improved Mn uptake and sequestration (Fig 4). In the glasshouse the application of PK fertilisers improved grain Mn by up to 22 mg kg^{-1} (56%); whilst in the field the application of P and K individually improved Mn concentrations by between 5-8 mg kg^{-1} (19%).

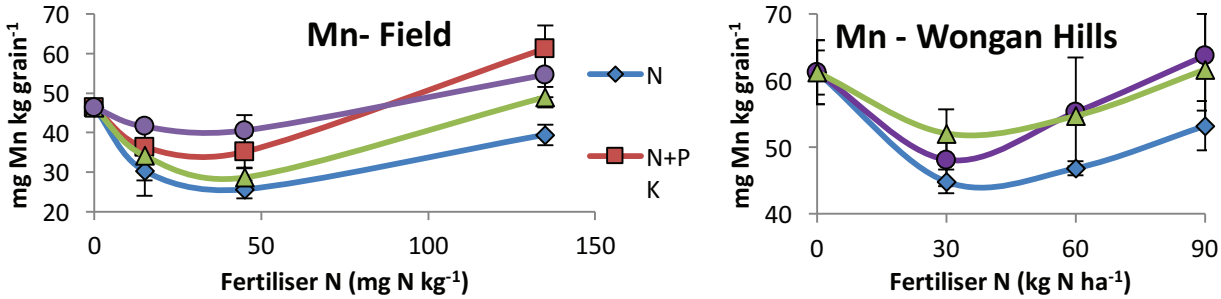

Figure 3. Grain Mn concentrations in Mace when grown under different NPK fertiliser regimes under glasshouse and field conditions. Data from field is from the Wongan Hills 'low nutrient' site. Error bars represent standard errors of the mean (n=3).

The application of NPK fertiliser was deleterious for grain Zn concentrations both in the glasshouse and field (≈ 5-15 mg kg^{-1}; 16-28% decrease) (Fig 4).

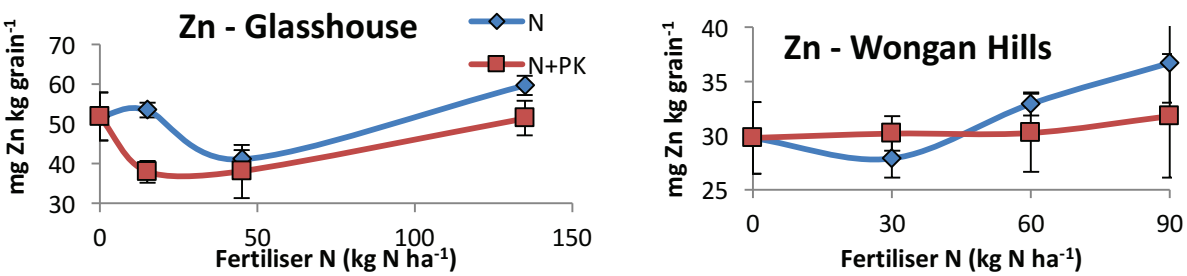

Figure 4. Grain Zn concentrations in Mace when grown under different NPK fertiliser regimes under glasshouse and field conditions. Data from field is from the Wongan Hills 'low nutrient' site. Error bars represent standard errors of the mean (n=3).

Discussion and Conclusions

The uptake and accumulation of trace elements varied when different combinations and concentrations of NPK fertiliser were applied (Figs 1-4). This confirms that manipulating macronutrient fertiliser regimes can aid in trace element uptake. In all three field trials there was no effect on grain yields when P and/or K fertilisers were applied at different N concentrations (Data not shown). This is a key consideration if manipulation of P & K is to be adopted for the purposes of increasing trace element concentration (per kg grain).

The data presented here indicates that the uptake of individual trace elements was influenced by different combinations of NPK fertilisers (Figs 1-4). For example, B and Mn uptake was enhanced by the addition of composite N+P fertilisers, particularly at high concentrations (e.g. 90 kg N ha^{-1} + 24 kg P ha^{-1}) (Figs 1 & 3). Conversely, the application of NPK fertilisers was detrimental for Cu and Zn uptake relative to 'N only' (Figs 2 & 4). Consequently, both fertiliser applications and residual NPK concentrations need to be carefully considered to optimise nutrient uptake and to avoid initiating deficiencies in some elements whilst trying to maximise the uptake of others. Furthermore, the observation of decreased Cu and Zn uptake when increased P and K concentrations are added to soil has some implications for the current state of Australian agriculture. During the latter part of the 20th century fertiliser use has increased exponentially (Angus, 2001; Cordell et al., 2013), while, at the same time, conservation farming practices such as no-till have increased the retention of P and K in many regions (Neuhaus, 2012; Weaver and Wong, 2011). Cu and Zn strongly interact with N in terms of plant uptake (Fageria, 2001), however, in these trials uptake decreased when P or K concentrations were increased (Figs 2 & 4). If such effects are widespread, continued build-up of P and K in soils has the potential to compromise Cu and Zn in grain and negatively impact human and animal nutrition.

While further studies are needed to confirm these results across differing growing environments and to explore whether manipulating trace element uptake is economically viable at a commercial scale, the results shown here indicate that increasing understanding of the interactions between macronutrients and micronutrients can lead to outcomes that are relevant for growers, fertiliser producers and crop biofortification industries. For growers, our findings provide an increased understanding of how management of NPK can maximise trace element uptake and this could become economically important if premiums are granted in the future for favourable trace element concentrations in grain. At a more basic level, application of our research findings may be a means to alleviate trace element deficiencies in crops. For fertiliser producers, the data supports continued investment in composite macronutrient/trace element fertilisers by providing information regarding nutrients and trace elements that can be combined for more efficient uptake e.g. NPK + Mn; NPK + B; N + Cu; N + Zn. For crop biofortification management, our data demonstrates that NPK nutrient management can alter the efficiency of biofortification processes.

In conclusion this research has demonstrated that trace element (B, Cu, Fe Mn and Zn) uptake and translocation in wheat can be both enhanced and compromised by the use of NPK fertilisers. Future research should endeavour to assess whether these observations are representative of wider trends both across Australia and globally.

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Lessons learnt about nitrogen and phosphorus from a 30 year study in a sub-tropical continuous cropping system on a vertosol

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Abstract

*A nitrogen (0, 40, 8*0 & 120 kgN/ha) x phosphorus (0, 5 (15 pre-1999), 10 & 20 kgP/ha) cropping rotation experiment was established on the central Darling Downs property "Colonsay" in 1985. In this time 23 grain crops were harvested along with 3 failed crops. The unfertilised control (0N:0P) produced 69.7 t/ha grain while 120 N:5(15)P gave maximum yield of 102.4 t/ha. Highest apparent fertiliser N recovery in grain of 48.5% was observed in response to 40N:10P which generated an additional 22 kg grain/kg applied N with an N balance of -511kgN/ha when compared with 0N:10P. Similar grain N recovery was reported for 80N:10P, but with a near neutral N balance of -24 kgN/ha. Maximum grain production in response to P was reported in the 80N:10P treatment with an extra 47.1 kg grain/kg applied P when compared with 80N:0P. 80N:10P gave a P deficit of -79 kgP/ha, with replacement P rate estimated at 13-14 kgP/ha/crop. A simple economic comparison with the unfertilised control 0N:0P, reveals maximum net return of $4,095/ha at 80N:5(15)P with a net loss of $1,026/ha for the 0N:10P treatment (grain @ $220/tonne farm gate, N @ $1.30/kg & P @ $3.50/kg). The addition of "replacement" rates of P where adequate N was applied increased net returns by more than $1,500/ha compared with no P application. The replacement P strategy maintained soil P levels at or above recognised critical levels.

Key words

Long term, Darling Downs, nutrient efficiency, economics

Introduction

Understanding the long term interaction between fertiliser N and P in southern Queensland is critical to optimising nutrient efficiency given evidence that optimal production and financial outcomes can be achieved with a "replacement" strategy. In contrast, departure from this strategy can result in adverse agronomic and financial outcomes impacting soil quality and yield potential. Agronomists and growers can deploy this information to retain more N in the system and to optimise P strategies over time.

Methods

The "Colonsay" experiment was established in 1985 as a factorial combination of four nitrogen (N) rates (0, 40, 80 and 120 kg/ha) at each of four phosphorus (P) rates (0, 5 (15 pre-1999)10, 20 kg/ha) with three replicates in randomised complete blocks. Further experimental details can be found in Lester (2012). The 5 kg P treatment commenced in 1999-00 on plots previously treated with 15 kgP/ha. As a result cumulative nutrient application from 1985-2013 comprised:

- 60, 940, 1,820 & 2,700 kgN/ha for 0, 40, 80 & 120N treatments n.b. 60 kgN/ha applied across all plots in 1991/92
- 0, 245, 230 & 460 kgP/ha for 0, 5(15), 10 & 20P treatments

To date 23 grain crops (12 sorghum, 6 wheat, 4 barley, 1 maize) have been harvested with another 3 crops (2 chickpea, 1 sorghum) unharvested due to crop failure.

Table 1. Soil chemical characteristics at "Colonsay", in Autumn 1985 (Lester 2012).

	0-0.1 m	0.1-0.6 m
$pH_{1:5}$ (H_2O)	8.5	9.0
Colwell P (mg/kg)	10	3
BSES P (mg/kg)	61	50
Nitrate N (mg/kg)	2.5	1.4

For this study the following calculations were adapted to gauge differences in nutrient efficiency:

(a) Apparent fertiliser N recovery in grain:

$$\frac{\text{[Cumulative grain N (treatment) – cumulative grain N (0N)]}}{\text{Cumulative N applied}}$$

(b) Additional grain production per kg additional N applied:

$$\frac{\text{[Cumulative grain production (treatment) – cumulative grain production (0N)]}}{\text{Cumulative N applied}}$$

(c) Nutrient balance:

Nutrient removed in grain – nutrient applied

Results and discussion

Production data, N efficiency and N balance

Table 2: Cumulative grain yield t/ha, [grain N uptake kg/ha], *apparent fertiliser N recovery in grain & (additional grain production per kg additional N applied)* after 23 harvests at "Colonsay" 1985-2013

N rate – kgN/ha/crop	P rate - kgP/ha/crop				
	0	10	5 (15)	20	Mean
0	69.7 [1,103]	68.7[1,024]	76.4 [1,175]	76.9 [1,195]	73.0 [1,124]
40	85.5 [1,489] *43.8% (16.8)*	88.0 [1,451] *48.5% (20.5)*	89.2 [1,432] *29.3% (13.6)*	90.9 [1,558] *41.3% (14.9)*	88.4 [1,483]
80	89.0 [1,633] *30.1% (10.6)*	99.8 [1,844] *46.6% (17.1)*	100.3 [1,820] *36.7% (13.1)*	99.9 [1,838] *36.6% (12.6)*	97.2 [1,784]
120	90.9 [1,715] *23.2% (7.8)*	96.1[1,845] *31.1% (10.1)*	102.4 ([1,921] *28.3% (9.6)*	100.3 [1,912] *27.2% (8.7)*	97.4 [1,848]
Mean	83.8 [1,485]	88.2 [1,541]	92.1 [1,587]	92.0 [1,626]	89.0 [1,560]
	N rate	P rate	N x P		
l.s.d	2.54 [51.08]	2.54 [51.08]	5.08 [102.17]	c.v. = 3.4% [c.v. = 3.9%]	
F pr	<0.001 [<0.001]	<0.001 [<0.001]	0.083[0.004]		

As expected, the addition of P generated a significant yield response based on starting (10 mg/kg) and current (8.9 mg/kg) Colwell P levels in the 0P control. There was a yield response between 10P and 5(15)P of 3.9 t/ha which was not observed when additional N was applied at these P rates. When the dataset was broken into pre-1999 when the 5(15)P treatment was 15 kgP/ha and post-1999 when this treatment was lowered to 5 kgP/ha there remains a significant difference in cumulative yield. This warrants further analysis given the small difference in total P inputs between these two treatments over the duration of the experiment. N generated incremental yield responses up to 80 kgN/ha. At higher N rates (80 & 120 kgN/ha) P response was maximised whereas at lower N rates response to P was lower.

The significantly lower grain N uptake in the 0N/10P treatment in contrast with higher P rates gave higher calculated N recovery for both 40 & 80N at 10 P although the effect is less at 120N. Apparent fertiliser N recovery in grain can be allied to agronomic efficiency described by Dobermann (2007) who asserted that it was more suited as a short term indicator of the impact of applied nutrients on productivity. When N balance is considered it was noted that added N was used very efficiently in this system up to and including the 80N rate where N is in negative balance other than where no P was added. At 120N a surplus is observed which is not accounted for by either profile residual mineral N or elevated organic carbon levels suggesting leakage from the system through denitrification which may account for losses of 60-80 kgN/ha for each event (Schwenke et al 2014) and leaching of residual N with Turpin et al (1998) reporting losses of around 30% of fertiliser N in a zero till system on a well-structured Darling Downs vertosol. The significant N deficit at 0 and 40 N was not accounted for by soil NO_3-N levels and while it would be logical to conclude that this deficit was met by N mineralised from organic matter, this is not supported by the surface (0-10 cm) organic carbon data. The other possibility is that some of the N deficit was bridged by contributions from the two failed chickpea crops one of which grew significant dry matter but was terminated by flooding.

At the lower (40)N rate it was unclear whether the addition of P improved grain production per kg applied N as the 0N/10P treatment gave no improvement in yield while other P treatments provided yield increase at 0N. At higher N rates however it appeared that the addition of some P did improve grain yield per kgN applied. Typically incremental yield per kgN applied decreased as N rate increased implying greater partitioning of N to protein at higher N rates and leakage from the system at higher than optimum rates.

Table 3: N balance – the deficit / surplus of N (kg/ha), (profile NO_3-N 0-90 cm) and *surface organic carbon % 0-10 cm after 2013 crop*

N rate – kgN/ha/crop	P rate - kgP/ha/crop			
	0	10	5 (15)	20
0	-1043 (37) *0.85*	-964 (37) *0.77*	-1115 (39) *0.93*	-1135 (40) *0.82*
40	-549 (58) *0.74*	-511 (47) *0.94*	-492 (38) *0.74*	-618 (54) *0.87*
80	187 (95) *0.88*	-24 (39) *0.77*	0 (76) *0.93*	-18 (72) *0.86*
120	985 (189) *0.83*	855 (121) *0.85*	779 (103) *0.91*	788 (121) *0.83*

P efficiency

The addition of P at the 0N rate provided unexpected results – at 10P there was no yield increase suggesting that yield was held back by N deficiency, however at 5(15)P a significant increase in grain production per kgP was observed. It is postulated that the additional P provided in the 5(15)P treatment in the early phases of the trial may have driven higher initial plant N uptake which remained cycling through this system – this is supported by higher yields observed for the 0N/5(15)P treatment and higher soil organic carbon % implying greater dry matter production over the duration of the experiment for the 0N/5(15)P treatment compared with 0N/10P. This yield response was also consistent with surface Colwell P levels –based on the Better Fertiliser Decisions for cropping data base (Speirs et al 2013), the 0N/10P treatment was in the responsive range for wheat on a black vertosol (90% relative yield) while the 0N/5(15)P treatment was outside this range and at the upper limit for 95% of maximum yield. This difference was also consistent for DGT P with a responsive reading for 10P and a near critical reading for 5(15)P .Subsurface Colwell P (10-30 cm) appeared to be more depleted in the 5(15)P treatment implying greater root exploration with this treatment – this was also supported by BSES P levels in the subsurface layer. We conclude that higher initial P inputs supported greater subsurface root exploration driving more efficient accumulation of sub-surface N reserves which in turn generated increased dry matter and grain production in an N-limited scenario. This was supported by the significant N x P interaction observed for grain N uptake in table 2.

Additional grain production /kgP was maximised at 80 kgN/ha where a deficit of 79 and 66 kgP/ha was observed for the 10 and 5(15)P treatments implying that the optimum P rate would be around 13 – 14 kgP/ha/crop in order to balance P removal and also to maintain soil P levels at or above recognised critical levels. Given the nature of the system and the evidence of P stratification, careful thought needs to be given to how the future P program would be applied.

Table 4: P balance – the deficit / surplus of P (kg/ha) & [additional grain production per kg additional P applied]

N rate – kgN/ha/crop	P rate - kgP/ha/crop			
	0	10	5 (15)	20
0	-202	17 [-4.4]	8 [27.3]	206 [15.6]
40	-248	-43 [10.9]	-31 [14.9]	160 [11.7]
80	-258	-79 [47.1]	-66 [46.1]	130 [23.7]
120	-264	-68 [22.3]	-72 [46.8]	129 [20.4]

Economic analysis

An economic analysis was conducted for each treatment by assigning a gross farm gate value of grain production and subtracting the cost of nutrients applied. Four scenarios were modelled including low grain price with low nutrient cost, low grain price with high nutrient cost, high grain price with low nutrient cost

and moderate grain price with moderate nutrient cost. Regardless, returns net of nutrient cost were optimised at 80N and 10 or 5(15)P. The analysis demonstrates that grain price was a more influential factor on returns from investing in nutrients than the cost of nutrients and that over the long run a strategy that replaced N removed and that maintained P at or about recognised critical levels was likely to optimise returns.

Table 5: Modelled economic returns at "Colonsay": 1985-2013 returns net of nutrient cost ($/ha).

kgN/crop	0 kgP/ha/crop				10 kgP/ha/crop			
Grain $/t	150	220	150	260	150	220	150	260
N $/kg	1.10	1.30	1.70	1.10	1.10	1.30	1.70	1.10
P $/kg	2.00	3.50	5.00	2.00	2.00	3.50	5.00	2.00
0	0	0	0	0	-610	-1,026	-1,300	-721
40	1,487	2,592	1,487	3,223	1,403	2,337	713	3,414
80	1,123	2,469	1,123	3,237	**2,287**	**4,045**	**1,597**	**5,592**
120	536	2,019	536	2,866	847	2,344	157	3,742
kgN/crop	5 (15) kgP/ha/crop				20 kgP/ha/crop			
0	514	615	-221	1,250	157	-30	-1,223	947
40	1,545	2,537	810	3,682	1,372	2,163	-8	3,698
80	**2,327**	**4,095**	**1,592**	**5,683**	1,840	3,259	460	5,154
120	1,765	3,682	1,030	5,355	1,022	2,471	-358	4,383

Conclusions

Results from Colonsay strongly endorse a nutrient replacement strategy in terms of optimising economic outcomes from investing in N and P. The experiment shows that where nutrients were managed in a balanced fashion little leakage can be expected from the system. Where nutrients were balanced it is practical to set an agronomic efficiency target for N fertiliser at 35- 45%. On P deficient soils, the application of greater than replacement rates during the building phase may improve harvesting of N from the soil and assist in retaining this N in the system for future use. In continuous cropping systems, while maintaining surface Colwell P at or around recognised critical levels has been a sound practice over the last 30 years, more research is required into which soil layers / P pools have been supplying P in order to maintain surface P at this level when in a negative net P balance. Consideration needs to be given to placement of P due to stratification arising from historical P placement strategies and accumulation of P in surface residues.

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Effect of deep placement of NPK briquette for rice yield maximization during Boro, T Aus and T Aman seasons at different locations in Bangladesh

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Abstract
Nine experiments were conducted at BRRI research farm at Gazipur, Barisal and farmer's field at Babuganj and Gournodi under Barisal district in Boro, T Aus and T Aman seasons, 2012 to evaluate the NPK briquette efficiency in rice production. Eight treatments were tested under each experiment. The experiments were laid down in randomize complete block design with three replications. The tested varieties were BRRI dhan29 in Boro, BRRI dhan27 in T Aus and BRRI dhan49 in T Aman season. USG and NPK briquettes were deep placed between four hills as per treatment after 7 days of transplanting. The results revealed that the deep placement of NPK briquette (2 x 2.4 g) increased about 10% yield and saved 37% N, 30% P, and 44% K than BRRI recommended rate of fertilizer in Boro season. Similarly, NPK briquette (1 x 3.4 g) produced 28% and 18% more rice yield over BRRI recommended rate of fertilizer for T Aus and T Aman season, respectively and also resulted in savings of 26-39% N. Deep placement of NPK briquette resulted in 4-10% higher rice yield and nutrient savings of 20-35 percent N, 18% percent P and 17-24% K over the recommended practice of NPK incorporation. Undiscounted benefit cost ratio (BCR) was 1.44, 2.40 and 3.20 for Boro, T Aus and T Aman seasons respectively when comparing at the same rates of N application. Thus, use of NPK briquette over NPK broadcast and incorporation was economically viable and efficient for rice cultivation.

Key words
Urea super granule (USG), Boro, T. Aus, T. Aman season

Introduction
Bhuiyan, et al. (1988) reported that deep point placement of USG resulted significantly higher grain yield of rice than split application of prilled urea. Further increases in grain yield, better N use efficiency (kg grain ha^{-1} N) and higher apparent N recovery occurred when the hole was closed after USG application. Similarly, Mohonty et al. (1990) reported that USG deep placement resulted additional grain yield of 1080, 510 and 350 kg ha^{-1} over prilled urea split in alternate wetting and drying, shallow low land and intermediate low land, respectively. Many strategies have been developed to increase the efficiency of urea-N use from fertilizer through proper timing, rate, deep placement, modified forms of fertilizer, and use of nitrification and urease inhibitors. Among them deep placement of urea fertilizer is one of the effective application method in reducing total N loss in the flood water and is likely to minimize losses through volatilization and surface runoff (De Datta & Craswell, 1982).

In rice cultivation system generally P and K fertilizer applied as broadcast but in NPK briquette it will be in point deep placement (Prasad and Prasad, 1983). Kapoor et al. (2008) reported that deep placed N-P briquettes gave significantly higher rice grain yield, total P and K uptake. They also found that closer spacing (20cm x 10cm) led to better utilization of P and K and provided opportunities for deep placement of N-P or N-P-K briquettes in soils with low available P. Bulbule et al. (2008) reported that grain yield of rice significantly increased when the crop was fertilized through briquettes (56-30-30 kg NPK ha^{-1}) as compared to the application of conventional fertilizers (100-50-50 kg NPK ha^{-1}). Placement of briquettes (in modified spacing 15-25cm x 15-25cm) markedly improved fertilizer use efficiency and it offset the addition cost involve in preparation and end placement of briquettes. Kadam et al. (2005) found higher amount of NPK in post harvest soil of NPK briquette used plot without tomato grown than with tomato grown plot.

In Bangladesh farmers generally do not always apply all three major nutrients in their field. When some farmers apply these nutrients the proportion is not maintained. With the concept of balance fertilization and

deep placement advantage towards higher nutrient use efficiency in rice NPK briquette is prepared with major nutrients. This paper discusses NPK briquette deep placement technology for higher rice yield as well as better utilization of applied fertilizer by the crop and indirectly to avoid environmental pollution through volatilization and surface runoff.

Methodology

Total nine field experiments were conducted at BRRI farm Gazipur, BRRI, Regional Station, Barisal and farmer's field at Babuganj and Gournodi of Barisal during Boro, T Aus and T Aman, 2012. Total eight treatments were tested under each experiment. The treatments were T_1 = AEZ fertility based BRRI recommended rate (RR) of prilled urea at three splits and P K S and Zn fertilizer was applied as basal at final land preparation, T_2 = One 2.70 g USG in Boro (N_{87}) or 1.8 g USG in T Aus and T Aman season (N_{58}) was placed at the centre of each four hills + AEZ fertility based BRRI RR of P K S and Zn fertilizer was applied as basal at final land preparation, T_3 = 2.40 g NPK briquette (two in Boro, one in T. Aus and T. Aman) was placed at the centre of each four hills (N:P:K ratio = 7.0:1.6:2.0 and doses of NPK = 87 kg ha^{-1} N, 20 $kgha^{-1}$ P and 25 $kgha^{-1}$ in Boro and 44 kg ha^{-1} N, 10 kg h^{-1} P and 12.5 kg ha^{-1} in T Aus and T. Aman, S and Zn as recommended, T_4 = One 3.40 g NPK briquette was placed at the centre of each four hills (N:P:K ratio = 9.1:2.4:3.5 and doses of NPK = 57 kg ha^{-1} N, 15 kg ha^{-1} P and 22 $kgha^{-1}$ K) and S and Zn as RR, T_5 = NPK S and Zn doses were same as T_3 but sources were USG, TSP, MP, T_6 = NPK S and Zn doses were same as T_4 but sources were USG, TSP, MP, T_7 = Absolute Control and T_8 = N alone from prilled urea. The experiment was laid down in RCB design with three replications. The tested varieties were BRRI dhan29, BRRI dhan27 and BRRI dhan49 in Boro, T. Aus and T. Aman season respectively. Transplanting was done by two seedlings per hill and the seedling age was 40, 30 and 35 days in Boro, T. Aus and T. Aman season respectively. All fertilizer was applied as per treatment before and after transplanting. The USG and NPK briquettes were deep pleased between four hills as per treatment after 7days of transplanting.

Table 1. Summary of treatments applied at different locations and across seasons.

Treat No.	Description	Location	Season	N Rate (kg/ha)	P Rate (kg/ha)	K Rate (kg/ha)
T1	BRRI Recommended	BRRI, Gazipur (d) BRRI, Barisal (e) Farmer's field at Barisal (f)	Boro	138a (all location)	(26d/30ef)b	(75d/30ef)b
			Aus	77a (all location)	(15d/11ef)b	(37d/17ef)b
			Aman	93a (all location)	(16d/15ef)b	42b
T2	USG (one-2.7 g briq)	All	Boro	78c	PK rate similar as T1 in respective season and location	
	USG (one-1.8 g briq)	All	T.Aus & T. Aman	52		
T3	NPK (two-2.4 g briq)	All	Boro	87c	20c	25c
	NPK (one-2.4 g briq)	All	T. Aus & T. Aman	43.5c	10c	12.5c
T4	NPK (one-3.4 g briq)	All	All	57c	15c	22c
T5	NPK (urea,TSP, MOP)	All	Boro	87a	20b	25b
	NPK (urea,TSP, MOP)	All	T. Aus & T. Aman	43.5a	10b	12.5b
T6	NPK (urea,TSP, MOP)	All	All	57a	15b	22b
T7	Absolute Control	All	All	0	0	0
T8	N alone	All	Boro	102	0	0
		All	T. Aus	77	0	0
		All	T. Aman	93	0	0

[a] Applied in three splits as urea, [b] P and K applied as TSP and MoP (KCl), [c] Deep point placed as urea briquette (USG) or NPK briquette

Results and Discussion

Grain yield and grain yield advantage (%) over RR of three locations with all treatments of Boro, T.Aus and T.Aman are significantly effected which has presented in Table 3-4 & 5. AEZ fertility based BRRI

RR treatment (NPKSZn) produced higher yield than without fertilizer and N alone treatment irrespective of locations and seasons. NPK briquette as deep placement increased grain yield than urea broadcast and incorporation during Boro season at three locations with equivalent N_{87} rate (Table 3). Similar yield increase was also observed in all locations in both T.Aus and T.Aman season with equivalent N_{57} (Table 4). It indicates that deep placement of NPK briquette has some yield advantage over urea application at equivalent N rate in wetland rice culture system. In Boro season, deep placement of NPK briquette with 87 kg N ha^{-1} produced higher grain yield than the higher level of BRRI recommended N_{138} rate having PKSZn even/uneven rate shown in Table 2. It means deep placement method saved fertilizer around 51 kgNha^{-1} with some increase yield advantage in Boro season. Similarly, in T.Aus and T.Aman season also showed some yield increase with less fertilizer as NPK briquette deep placement as compared to higher level of recommended N rate (Table 3). Again, deep placement method saved N fertilizer 20 kg ha^{-1} in T.Aus and 36 kg ha^{-1} in T.Aman season (Table 1). Deep placement of NPK briquettes results similar or even higher grain yields with 10, 28 and 18% in Boro, T.Aman and T.Aus season respectively less fertilizer than urea applied as broadcast (Table 4). A partial budget analysis was done to determine the economic benefit of NPK briquette over urea broadcast and incorporation. Table 5 revealed that additional yields obtained from NPK briquette deep placement were 577 kg/ha, 713 kg ha^{-1} and 880 kg ha^{-1} in Boro, T.Aus and T. Aman production, respectively and thus additional returns (Tk ha^{-1}) were Tk 8655, Tk 10695 and Tk 13200, respectively. On the other hand by using NPK briquette for rice production additional cost were incurred Tk. 3540, Tk. 3144 and Tk. 3144 in Boro, T.Aus and T.Aman production, respectively. Therefore, in all seasons, positive net returns were obtained from NPK briquette placement for rice cultivation. Table 5 also showed that undiscounted BCR were highest (3.20) in T. Aman production followed by 2.40 in T. Aus production. Finally, it may conclude that use of NPK briquette over urea broadcast and incorporation was economically viable and efficient for rice production.

Conclusion

It may be concluded that NPK briquette deep placement in wet land rice culture enhance to obtain expected potential yield with less amount of fertilizer than the conventional use of urea, TSP and MoP in rice cultivation. Deep placement NPK briquette leads to the accumulation of nutrients in the reduced zone of soil and subsequently these nutrients are utilized efficiently by rice plants for better growth and increased yield. Thus the use of NPK briquettes promotes towards balanced fertilization, saves fertilizer and reduces environmental pollution and may be considered as environment friendly technology.

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Table 2. Effect of different treatments on the grain yield of BRRI dhan29 in Boro, 20 12 at different locations.

Treatments	BRRI, Gazipur	BRRI, Barisal	Farmer's field, Barisal
T_1=Rec. fertilizer rate	7.00 b	6.99 ab	6.67 bc
T_2=USG N_{52} kg ha^{-1} + Rec. PKSZn	7.13 ab	7.15 a	7.03 b
T_3=(2x2.40) NPK briqutte N_{87}	7.47 a	7.29 a	7.94 a
T_4=3.40 g NPK briqutte N_{57}	5.92 c	6.43 b	6.13 c
T_5= NPK same at T_3 from urea, TSP and Mop	6.96 b	6.89 ab	7.16 b
T_6= NPK same at T_4 from urea, TSP and Mop	6.12 c	6.26 b	6.22 c
T_7= Abs. control	3.89 d	3.20 c	4.14 d
T_8= Only N	5.88 c	6.19 b	6.88 bc

Figures in a column means followed by different letters differ significantly, whereas figure with common letter(s) are not significantly different at the 5% level by DMRT.

Table 3: Effect of different treatments on the grain yield of BRRI dhan49 and BRRI dhan48 during, T. Aman and T. Aus season 2012 respectively at different locations.

Treatments	BRRI, Gazipur		BRRI, Barisal		Farmer's field, Barisal	
	T. Aus	T. Aman	T. Aus	T. Aman	T. Aus	T. Aman
T_1=Rec. fertilizer rate	3.24 c	4.20 bc	2.84 d	4.77 bc	2.73 b	4.40 b
T_2=USG N_{52} kg ha^{-1} + Rec. PKSZn	3.57 b	4.44 b	3.34 b	5.26 ab	2.90 b	4.94 ab
T_3=(1x2.40)NPK briqutte N_{44}	3.20 c	3.89 c	3.10 c	5.54 ab	2.96 b	4.22 b
T_4=3.40 g NPK briqutte N_{57}	3.93 a	4.85 a	3.58 a	5.70 a	3.72 a	5.19 a
T_5= NPK same at T_3 from urea, TSP and Mop	2.96 d	3.27 d	2.80 d	4.68 bc	2.72 b	4.01 bc
T_6= NPK same at T_4 from urea, TSP and Mop	3.18 c	4.03 d	3.04 c	4.70 bc	2.87 b	4.37 b
T_7= Abs. control	2.13 e	2.96 e	2.02 e	3.60 d	2.38 d	3.16 d
T_8= Only N	2.51 d	3.30 d	2.47 d	4,29 cd	2.51 cd	3.55 cd

Figures in a column means followed by different letters differ significantly, whereas figure with common letter(s) are not significantly different at the 5% level by DMRT.

Table 4: Effect of different treatments on the grain yield advantage (%) over recommended fertilizer rate (RFR) average of three locations during Boro, T Aman and T. Aus season,

Treatment	Avg. yield increase in Boro over RFR (%)	Avg. yield increase in T Aman over RFR(%)	Avg. yield increase in T Aus over RFR(%)
T_1=Rec. fertilizer rate	0.0	0.00	0.00
T_2=USG N_{52} kg ha^{-1} + Rec. PKSZn	3.25	11.43	9.41
T_3= NPK briquette N_{87} (Boro) and N_{44} (T Aus and Aman)	10.06	5.47	-1.85
T_4=3.40 g NPK briquette N_{57}	-10.51	27.99	17.69
T_5= NPK same at T_3 from urea, TSP and Mop	1.82	-4.45	-10.97
T_6= NPK same at T_4 from urea, TSP and Mop	-9.89	3.49	-2.02
T_7= Abs. control	-45.51	-25.21	-27.45
T_8= Only N	-8.04	14.50	16.83

Table 5. Partial Budget Analysis of NPK Briquette for rice production in different seasons over urea broadcast and incorporation.

Season	NPK Briquette	Additional Yield (t/ha)	Additional Return (Tk/ha)	Additional Cost (Tk/ha)		Total Cost (Tk/ha)	Net Return (Tk/ha)	Undis-counted BCR
				Cost for Briquet. Manuf	Labor Requirement			
Boro	2.4g: 87-20-25	577	8655	1140	2400	3540	5115	1.44
T. Aus	3.4g: 57-15-22	713	10695	744	2400	3144	7551	2.40
T. Aman	3.4g: 57-15-22	880	13200	744	2400	3144	10056	3.20

Note: Estimated price of paddy was Tk 15/kg, Manufacturing cost of NPK briquette was Tk 6/kg, Labor required for NPK briquette placement was 8 man-day/ha and wage rate of labor was Tk 300/day.

Adding sulfur to finished fertilisers: inside or outside?

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Abstract
The world has rapidly moved away from sulfur containing single superphosphate and ammonium sulfate to high analysis ammonium phosphates and urea. This move, together with higher yields and lower atmospheric inputs of S has led to increasing incidence of sulfur deficiency which not only affects yield, but also product quality. Addition of fine elemental S to fertilisers during manufacture, or to the finished product, has potential problems because of the explosive nature of elemental S dust. Various processes have been developed to safely deliver the S, each having advantages and disadvantages.

A glasshouse experiment has been conducted to evaluate the sulfur availability to a maize crop grown for 5 weeks in a glasshouse when applied as a surface coating to, or incorporated in the fertiliser granule. Maize yields were not different between surface and incorporated treatments with TSP, DAP or MAP fertilises, Plant yields were not different from powdered elemental S applied alone. By contrast, yield with sulfur bentonite was not significantly different from the –S control. Tops S content and % apparent fertiliser S recovery also did not differ between coated and incorporated S fertilisers or between fertilisers.

For elemental S to be agronomically effective when added during, or post manufacturing it has to be of fine particle size. The process used depends on technology available in fertiliser plants, transport conditions and local S needs. These results suggest that local S coating of finished fertilisers is a feasible alternative to S incorporation undertaken at a central fertiliser plant.

Key words
Ammonium phosphate, triple superphosphate, sulfur oxidation

Introduction
Increasing freight and spreading costs have focused attention in fertiliser manufacture to producing products with high nutrient density. Elemental S is an almost ideal fertiliser as it contains 100% nutrients. Elemental S must be oxidized to sulfate before it is available to plants and since microorganisms carry out this process it is moisture and temperature dependant, as is the crop demand for S. The rate of oxidation is also dependent on the particle size of S. This means that there is great scope to manage the release rate of sulfate to the plant to maximize plant uptake and minimize losses by surface runoff and leaching.

Farmers in many parts of the world have readily accepted sulfur enhanced ammonium phosphate fertilisers and these fertilisers commonly contain a mixture of sulfate and elemental S. Much of the developmental work on sulfur enhanced fertilisers has been undertaken by Shell at the International Fertiliser Development Center where the process has been used with pre-neutralizers (PN) and pipe cross reactors (PCR) and combined PN/PCR units with S concentration ranging up to 20%. A significant feature of the process is that elemental S is distributed throughout the fertiliser granule (Blair, 2009).

Many fertiliser have been marketed which have elemental S coated on to TSP and MAP. One problem encountered with these products has been abrasion of the coat during transport and spreading (Dana, 1994b). Because of the explosive nature of fine elemental S dust considerable precautions need to be taken to safely add elemental S during manufacture. Recent advances in wet grinding technology (e.g. US Patents 4372872A, US8679219 B2) have reduced this hazard and it is now feasible to safely prepare fine elemental S.

The aim of the experiment reported here was to evaluate the availability of S to maize when either coated onto the surface of a finished fertiliser or incorporated into the fertiliser granule during manufacture.

Materials and Methods

A Tenosol soil of granitic origin, known to be S deficient was collected from the Kirby Experimental Station of the University of New England, Armidale, Australia. The soil was collected from the 0-30cm horizon, dried, ground, and passed through a 2.0mm sieve. The total S concentration in the soil was 204 µg/g and KCl-40 S was 1.3 µg/g

PVC plastic pots with an inside diameter of 15 cm and 12 cm deep were filled with 1.3 kg of soil and the pots watered to field capacity and above for two weeks to remove sulfate. The solid fertiliser treatments shown in Table 1 were applied to the surface of this soil layer along with a small amount of soil which had previously received elemental S to act as an inoculum for *Thiomonas*, and an additional 200 g of soil placed on top of the 1.3 kg soil.

TSP was coated with <75 mm elemental S or the S was incorporated into the granule in the granulator during manufacture. MAP and DAP were coated with <75 mm elemental S or the S was added as molten S into the preneutraliser during manufacture so that the S was incorporated throughout the granule. All fertilisers, except S bentonite contained some sulfate S as shown in Table 1.

There were 9 treatments with three replicates and all treatments, except the control, received S at 27 mg/pot (equivalent to 15 kg S/ha) based on pot surface area. N, P, K and Mg were applied to all treatments at rates of 80, 45, 20 and 5 kg/ha, respectively as Urea, DAP, KCl, and $MgCl_2$. Additional ammonium nitrate was applied throughout the five week trial to ensure that nitrogen deficiency did not interfere with the results. The pots were maintained at field capacity for three weeks to initiate S oxidation.

Four 4 day old-germinated seeds of maize were sown on in each pot to a depth of 2-2.5 cm and the pots watered to near field capacity. After one week plants were thinned to two healthy plants per pot. The moisture content was adjusted to field capacity and maintained at that moisture with tap water for the majority of the experiment. Excess water was applied at intervals to promote leaching of sulfate. The temperature of the glasshouse was maintained at 20-30oC throughout the experiment.

The design was a randomized block with three replicates. Pots were re-randomized every week within a replicate to minimize glasshouse variation.

Table 1. Description of S sources evaluated

Fertiliser	Analysis				
	%N	%P	%S	%Sulfate	%Elemental
Control	0	0	0	0	0
S/bentonite	0	0	90	0	90.0
TSP S coated	0	17.8	12.9	1.0	11.9
TSP S incorporated	0	17.8	10.8	2.5	8.3
MAP S coated	8.5	18.7	14.3	2.4	11.9
MAP incorporated	11.7	19.0	11.6	3.8	7.8
DAP S coated	15.3	17.1	14.4	2.5	11.9
DAP S incorporated	16.0	14.8	12.0	3.0	9.0
Elemental S	0	0	100	0	100.0

Maize was harvested approximately 5 weeks after planting by cutting plants 1.5 cm above the soil surface. The harvested tops were dried at 60oC until constant weight. The dry plant tops was weighted and ground to pass a 1 mm screen, Ultrawave Microwave digested and S concentration measured in an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES).

Results and Discussion

Maize tops yield did not differ significantly between S coated or S incorporated fertilisers or between fertiliser type (TSP, MAP, DAP) and the tops yield in these treatments did not differ from powdered elemental S (Table 2).

Tops S content was not significantly different between the control and S bentonite treatments and there was no significant difference between coated and incorporated S in any fertiliser or between fertilisers (Table 2). The highest tops S content was in the elemental S treatment due to its higher tissue S concentration (data not presented). Apparent fertiliser S recovery was lowest for S bentonite and, as for the other parameters measured, there was no significant difference between coated and incorporated S in any fertiliser. Tops C content and apparent fertiliser S recovery was highest in the elemental S treatment presumably because the powder was more accessible for oxidation and for plant root interception.

In the short 5 week period of this experiment S bentonite released little S as sulfate which is similar to the findings of Dana et al. (1994a) who found that S oxidation from S bentonite and sulfur coated urea (SCU) was not fast enough to meet initial plant demand, although they had a higher residual value in the following crop.

The results of Dana et al. (1994b) indicate the importance of bonding strength when S is coated onto finished fertiliser products. They found that the bonding process used in the Hifert Goldphos 10 fertiliser (TSPS) resulted in a coating which not only delayed the S release rate but also significantly reduced the rate of Ca and P movement from the TSP granules under laboratory leaching conditions.

Table 2. Maize tops yield (g/pot), S content (mg/pot) and apparent fertiliser S recovery (%).

Treatment	Tops yield (g/pot)	Tops S content (mg/pot)	Apparent fertiliser S recovery (%)
Control (+P-S)	8.4 c[A]	4.9 e	-
S Bentonite	7.7 c	5.5 de	2.1 d
TSP S coated	10.3 bc	6.6 cde	6.1 cd
TSP S incorporated	13.3 ab	8.4 bcd	11.6 c
MAP S coated	12.1 bc	8.6 bcd	13.5 bc
MAP incorporated	12.7 bc	10.0 bc	18.8 b
DAP S coated	12.5 bc	9.88 bc	18.5 b
DAP S incorporated	14.2 ab	10.6 bc	21.1 b
Powdered Elemental S	13.6 ab	15.8 a	40.6 a

A Numbers within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test.

Among the adhesive materials used to coat TSP Dana et al. (1994b) found that polyvinal acetate and sodium lignosulfonate were the most effective and it is of interest to note that the initial rate of fertiliser S uptake from these products was greater than from elemental S alone of the same particle size. This is most likely due to the enhanced oxidation rate of elemental S when in intimate contact with P, as reported by Lefroy et al (1997).

These results suggest that local S coating of finished fertilisers is a feasible alternative to S incorporation undertaken at a central fertiliser plant.

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Response to deep placed P, K and S in central Queensland

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Abstract
Two field experiments were established in central Queensland at Capella and Gindie to investigate the immediate and then residual benefit of deep placed (20 cm) nutrients in this opportunity cropping system. The field sites had factorial combinations of P (40 kg P/ha), K (200 kg K/ha) and S (40 kg S/ha) and all plots received 100 kg N/ha. No further K or S fertilizers were added during the experiment but some crops had starter P. The Capella site was sown to chickpea in 2012, wheat in 2013 and then chickpea in 2014. The Gindie site was sown to sorghum in 2011/12, chickpea in 2013 and sorghum in early 2015. There were responses to P alone in the first two crops at each site and there were K responses in half the six site years. In year 1 (a good year) both sites showed a 20% grain yield response to only to deep P. In year 2 (much drier) the effects of deep P were still evident at both sites and the effects of K were clearly evident at Gindie. There was a suggestion of an additive P+K effect at Capella and a 50% increase for P+K at Gindie. Year 3 was dry and chickpeas at Capella showed a larger response to P+K but the sorghum at Gindie only responded to deep K. These results indicate that responses to deep placed P and K are durable over an opportunity cropping system, and meeting both requirements is important to achieve yield responses.

Key words
Nutrient use efficiency, cropping systems, removal-to-use, fixed nitrogen, rotations.

Introduction
The northern Australian cropping region covers around 4M ha and is characterized by summer rainfalls on relatively heavy soils, which support summer crops (sorghum, mung bean) and winter crops (wheat, barley. chickpea) growing on incident or stored soil water respectively. Native soil fertility was high, especially on the Vertosols, but this has declined over time such that a significant proportion of the crop nitrogen (N) requirement is now supplied by fertilisers (Dalal and Probert 1997). The reliance on stored subsoil water by winter crops means that roots growing in the moist subsoil exploit largely immobile K and P from that layer, while the drier topsoil reserves are not used. Unless deep soil samples are taken, these deficiencies can go unnoticed.

Over the long term that has been little P or K used, with the consequence that the exports of P and K are significant and primarily related to the grain yield of the crop. The removal of crop nutrients depends on the grain concentration and yield, with average rates P removal are around 2.9-3.2 kg P/t of grain for wheat, sorghum and chickpea, but K removal in chickpea (11.0 kg K/t) was at least twice that for wheat (4.1 kg K/t) and sorghum (3.1 kg K/t (Bell and Moody 2001). On average, cropped soils across all these northern regions contained 55% (±5%) of the exchangeable K reserves of the uncropped reference sites. This depletion is resulting in increasingly complex nutrient management decisions for growers (Bell et al. 2010, 2012). These results clearly confirm the impacts of multiple nutrient depletion and therefore declining soil fertility and so current research is evaluating strategies such as deep placement of K to address nutrient stratification.

The wetting and drying pattern of the soil, which in turn drives root growth and nutrient removal in the northern region means that the subsoils have become largely depleted of nutrients. The drier topsoils may show adequate soil test values, so that extractable K in the subsoil (10-30 cm) needs to be measured to determine K availability for crop growth (Bell et al. 2009, Moody et al. 2010). Revised soil testing protocols to take account of stratified nutrients have been proposed in some regions (Brennan and Mason 2006).

In response to these challenges, the hypothesis was developed that relatively high rates of nutrients could be place in the subsoil (10-30 cm) to provide for several crop phases. The initial application would see some disturbance, and the duration of the responses is uncertain. The experiments reported here aim to assess the long-term responses to P, K and S, alone and in combination, when placed at 20 cm.

Methods

Sites were selected in farmer's paddocks at Gindie (approx. 22 km south of Emerald) and Capella (approx. 50 km north of Emerald). Both sites had low P, K and S, especially in the subsoil layers (Table 1). The experiments were established by deep banding (~20 cm deep) using P (40 kg P/ha), K (200 kg K/ha) and S (30 kg S/ha) alone and in combination, and comparing performance to a deep ripped with no nutrients (control). Deep banding occurred during the 2011winter fallow and the bands were 50 cm apart. The sites were managed by the farmer as they would for the rest of the field, with crop selection and agronomic management following normal commercial practice for that soil type and region.

Biomass samples were taken to estimate crop growth and nutrient acquisition. Yield and grain nutrient concentration were also take by hand sampling to determine economic performance and nutrient removal. Crop sequences to date have been chickpea-wheat-chickpea-sorghum and sorghum-chickpea-sorghum at Capella and Gindie, respectively. No additional deep nutrients were provided after the initial treatments were applied, although some in-furrow fertilizers were applied at crop seeding, and this was across all experimental treatments.

Table 1 Soil test values at the start of the experiments at Gindie and Capella central Queensland.

		Gindie		Capella	
Analyte	unit	0-10 cm	10-30 cm	0-10 cm	10-30 cm
pH Ca		7.2	7.8	8.1	8.3
CEC	cmol(+)/kg	35.3	38.4	73.7	74.6
OC	%	0.6	0.5	0.7	0.7
Colwell P	mg/kg	13	<5	10	<5
BSES-P	mg/kg	10	5	14	9
Ex-K	cmol(+)/kg	0.17	0.07	0.46	0.16
KCl-40 S	mg/kg	3	2	3	2
DTPA Zn	mg/kg	0.2	0.1	0.3	0.1

Crop biomass and grain yields were measured, along with nutrient concentrations in the biomass, so that nutrient uptake values could be estimated.

Results and discussion

The soil test values for the two sites (Table 1) indicate low to very low Colwell P values, below the 95% critical soil test range for sorghum (17-30 mg/kg), field pea (21-28 mg/kg) and wheat (18-30 mg/kg) (Bell et al. 2013a, Bell et al. 2013b), while the ex-K values are around the critical soil test range for northern Vertosols (~0.4-0.6 cmol(+)/kg), (Guppy pers. comm.) at Gindie and Capella. The sulfur soil test values are near the critical range (2.4-3.2 mg/kg, Anderson et al. 2013) are also low, and so these sites reflect those with multiple subsoil deficiencies (Bell et al. 2010).

The grain yields over the six site years are summarized in Table 2. At Capella, there was little response to S alone but P alone showed a strong response in the first and second year crops, but not in the third crop. The response to K alone was significant only on the 2013 wheat crop, however when P and K were supplied together (as PK or PKS) the numerically highest yields were seen. Similar patterns were seen at Gindie in the first two crops, with combined P and K giving the highest yields, but in the 2014/15 sorghum K rather than P dominated this response.

Results have differed between sites, and among crops at a site. In the initial crop year, with good moisture availability, both sites showed a 20% grain yield response to deep P. While no other nutrients affected grain yields there was a suggestion of an additive effect of deep K at Capella in chickpea biomass, but this did not translate into a yield difference. Despite low soil S, neither site responded to applied S at either site.

In the much drier 2013 season (no in-crop rainfall after planting), effects of deep P were still evident at both sites (14% in Gindie chickpeas and 8% in Capella wheat), but effects of K were clearly evident only at Gindie. There was a suggestion of an additive P + K effect at Capella and a very significant additive effect of P + K at Gindie. The Gindie site was particularly interesting, as while the only nutrient limit at that site in the previous sorghum crop was P, the 2013 data suggest K availability was a greater limitation in the current

chickpea crop (14% response to P but 27% response to K), while the additive effects of residual P and K were substantial (51% grain yield increase).

The reasons for the greater K response in 2013 could be related to seasonal conditions (no effective in-crop rainfall to allow access to shallow K reserves), crop species differences in K requirements (currently not known) or even agronomic factors such as crop row spacing (which influence available soil volume for root exploration). Regardless, of the nature of the interactions, these data illustrate that as soils reserves decline, it is essential to apply the right combination of fertiliser nutrients to maximise crop productivity and seasonal water use efficiency.

Year 3 was also a dry year, and chickpeas at Capella showed a response to P and K together, rather than when they were supplied alone. At Gindee, the sorghum crop did not response to added P, although the K responses were still sustained. The responsiveness of sorghum, which is grown on wide rows, is less clear as with a wet soil profile, the wider rows allow plants access to larger soils volumes, so that if the K supply is limited, the crop can extract adequate K even though it is at a lower soil concentration. The declining P response in year 3 at both sites suggests that the residual P may be approaching exhaustion after three crops, but the K rates applied (200 kg k/ha) are still available although the uptakes seen (Figure 1) are approaching the amount applied.

Table 2 Grain yields (t/ha) for crops grown with the various deep placed nutrition 2011 to 2015.

Site and crop/year	Control	K	P	S	PK	PS	KS	PKS	LSD (P<0.05)
				'Stranraer' Capella					
Chickpea 2012	2.33	2.34	2.75	2.32	2.89	2.79	2.30	2.83	0.17
Wheat 2013	2.08	2.19	2.25	2.19	2.36	2.25	2.20	2.34	0.09
Chickpea 2014	1.51	1.59	1.57	1.53	1.69	1.65	1.60	1.75	0.10
				'Bendee' Gindie					
Sorghum 2011/12	2.32	2.39	2.78	2.36	2.90	2.81	2.35	2.81	0.14
Chickpea 2013	1.15	1.47	1.32	1.21	1.74	1.18	1.52	1.61	0.26
Sorghum 2014/15	2.94	3.40	2.99	2.90	3.38	3.25	3.19	3.25	0.20

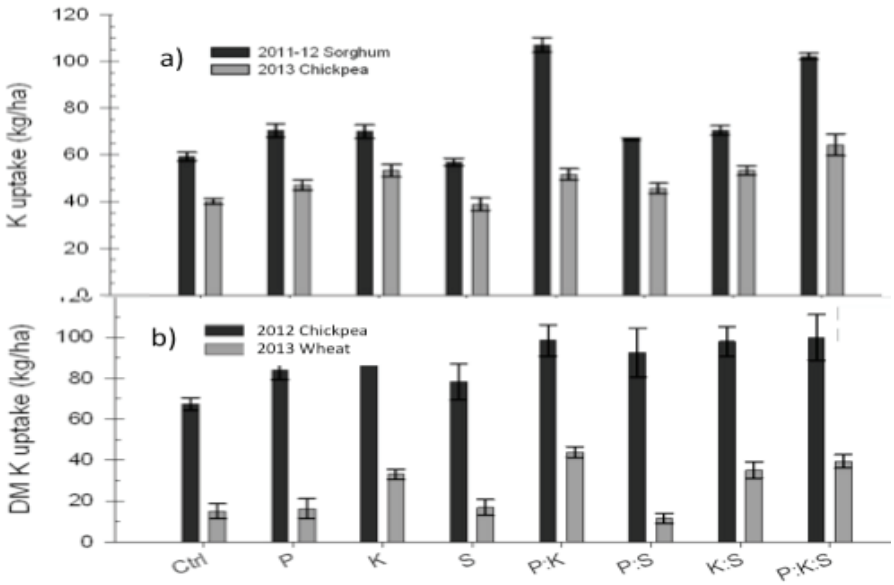

Figure 1. Uptake of K in total dry matter in response to deep placed nutrients at a) Gindie in 2011 and 2013, and b) Capella in 2012 and 2013.

Conclusion

Nutrients deep placed (20 cm), in this case P and K, showed responses over a range of crops and environmental conditions. Responses were more apparent in drier years where crop roots drew water and nutrients from the subsoils rather than from a larger soil volume. These responses were seen for at least three crops over four years, indicating the feasibility of deep placement at the start of a cropping cycle to meet nutrient demands in this opportunity cropping system.

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Modelling soil organic carbon 2. Effects of stocking rate, nitrogen fertiliser and stubble retention on changes across farming systems in eastern Australia

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Abstract
The level of soil organic carbon (SOC) attained under agriculture largely depends upon rates of carbon input and its decomposition under various management options such as fertiliser and stubble management. In this study, we used the APSIM-Wheat and APSIM-Agpasture models to simulate changes in a range of generic crop and pasture (grass-legume) management systems across 9 locations in eastern Australia. We examined how nitrogen fertilization, stubble management and stocking rate affect SOC and what strategies might be employed by farmers to increase SOC sequestration across eastern Australia. We modelled a continuous cropping regime, a continuous grazed pasture and mixed 12-year cropping and pasture rotation. Continuously grazed pasture resulted in SOC gains over a 60 year period, except at Roma. However, increasing stocking rate generally decreased the gain in SOC at all sites. The effect of stocking rate on the rate of decline in SOC was much reduced with N fertiliser and stubble incorporation. The longer 8 years of pasture provided larger increases in SOC, but the effects of increasing stocking rate and fertilisation and stubble incorporation rates were similar. It was found that the higher the annual rainfall, the greater the potential to increase SOC in grazed pasture or crop-pasture rotation systems, however high temperature appeared to reduced gains in SOC, with an apparent optimal mean temperature at which the highest SOC increase can be obtained.

Key words
Simulation, mineral nitrogen, crop, pasture, rotation, APSIM, farming systems

Introduction

The effects of environmental variables, agricultural management practices and ecosystems on SOC have been widely studied (Eclesia et al. 2012). However, the effects of the environmental factors on SOC dynamics remain inconclusive (Dalias et al. 2001). Changes in temperature and rainfall alter crop biomass production, decomposition rates and thus ultimately the resultant changes in SOC content. In general, an increase in precipitation is expected to increase SOC due to increased net productivity, hence more carbon input to the soil occurs through below ground root turnover and deposition of above ground litter. On the other hand, an increase in temperature may be unfavorable for SOC sequestration due to higher decomposition rates of SOC (Davidson and Janssens 2006). In dry and hot environments such as the Australian inland farming regions, high decomposition rates and low amounts of crop residues limit soil organic matter increase (Mele and Carter 1993). Therefore, it is a challenge for farmers to maintain or increase SOC while obtaining agronomic profitability in such an environment.

In Part 1 of this study, we evaluated the performance of the Agricultural Production Systems sIMultor (APSIM) across a diverse range of pasture and cropping systems in eastern Australia (O'Leary et al. 2015). In this paper (Part 2) we explored the extent that various crop and pasture management options affect changes in SOC from sub-tropical to a temperate environment. Specifically, we examined how nitrogen fertilization, stubble management and stocking rate are expected to affect SOC.

Methods

We selected a study area providing a significant climatic gradient in eastern Australia defined by 9 key locations, each representing geographically important and significant regions in terms of agricultural productivity in Australia. The study area included central and southwest Queensland (Roma and Dalby), northern New South Wales (Narrabri and Nyngan), central and southern New South Wales (Deniliquin and Wagga Wagga), northern Victoria (Rutherglen), south western Victoria (Horsham and Hamilton).

APSIM was set up to simulate three faming systems, i.e. continuous-cropping, continuous-grazed-pasture and mixed cropping and grazed-pasture systems. The primary aim of this study was to investigate the effects of farming management on the change in soil organic carbon (SOC) under different farming systems in different environments. Therefore, it was essential to first establish an equilibrium SOC level for each site so to make an unbiased comparison of the changes across different management, farming systems and locations. To achieve this, we ran the model for a continuous wheat cropping system for 50 years before implementing any treatments. In these equilibrium simulations, we applied 25% incorporation of wheat stubble and 90 kg N/ha at sowing. The rate of stubble incorporation represents a farming practice where most of the stubble is not returned to the field and the nitrogen application is a rate typically applied across eastern Australia. For the soil depth, initial soil water content at the beginning of the equilibrium simulation was set up as 50% of plant available water capacity and initial amount of nitrate and ammonium at 117 kg N/ha and 63 kg N/ha respectively. For continuous cropping, fertiliser applications and stubble management are the major management options available to farmers that can influence SOC sequestration (Van Wesemael et al. 2010). Our simulated management practices included eight N application rates (20, 45, 70, 95, 120, 145, 170 and 200 kg N kg/ha) and five stubble incorporation rates (0, 25%, 50% 75% and 100%). The fertiliser was applied once at sowing. Incorporation rates denoted the proportion of remaining residue incorporated into the soil by tillage into the fresh SOC pool by tillage. The continuous grazed pasture was established to represent a typical grass-legume pasture regime applicable in southern Australia but which is generic enough to mimic pasture production in northern Australia. We simulated a low productivity pasture under 13 stocking rates from 0 to 12 ewes/ha in 1 ewe/ha increments. A twelve year rotation was established for the mixed cropping and grazed-pasture systems. In eastern Australia, the minimum length for crop or pasture is typically four years. Therefore, we simulated a series of 5 rotations with 4, 5, 6, 7, and 8 years of pasture followed respectively by 8, 7, 6, 5 and 4 years of cropping which are denoted as 4P8C, 5P7C, 6P6C, 7P5C and 8P4C.

Results and Discussion

The rate of increase in SOC varied from site to site where the zero-SOC change line showed marked differences from the amount of stubble incorporation and nitrogen application between locations (Figure 1). For example, at Hamilton it required 140 kg N/ha and 75% stubble incorporation to maintain the current SOC level, whereas at Wagga Wagga it required only 70 kg N/ha and 25% stubble incorporation to maintain SOC levels. At Roma, the northern-most site, there was little increase in SOC from increasing N above 70 kg N/ha whereas most other sites showed benefits above 70 kg N/ha. The biggest factor in boosting SOC was the level of stubble incorporation as the range of SOC changed from 0% to 100% stubble incorporated varied from 150 to over 300 kg/ha/yr. Complete stubble removal (0% stubble incorporation) caused SOC declines across all sites. In the warmer and wetter site (Roma) and warmer dry site (Nyngan), the greatest SOC increase was about 110 kg/ha/yr under the highest rates of N application and stubble incorporation, while at other sites, such as Wagga and Horsham, the greatest SOC increase was over 300 kg/ha/yr. However, at the coldest site (Hamilton), continuous cropping resulted in soil carbon decreases at all but the very highest rates of N application and stubble incorporation. It is notable that at 100% stubble removed soils at all our study sites become a net contributor to atmospheric CO_2, except at a very high N application (e.g. >180 kg N/ha at Horsham).

Continuous pasture (grazed or un-grazed at 0 ewes/ha) generally resulted in positive gains in SOC over the 60 years (Figure 2). However, increasing stocking rate generally decreased SOC change rates at all sites. There was however one location where SOC was not increased by continuously un-grazed pasture (Roma) and grazing at any stocking rate resulted in SOC losses. The effect of stocking rate on the change in SOC can be well described by a general linear relationship (Figure 2).

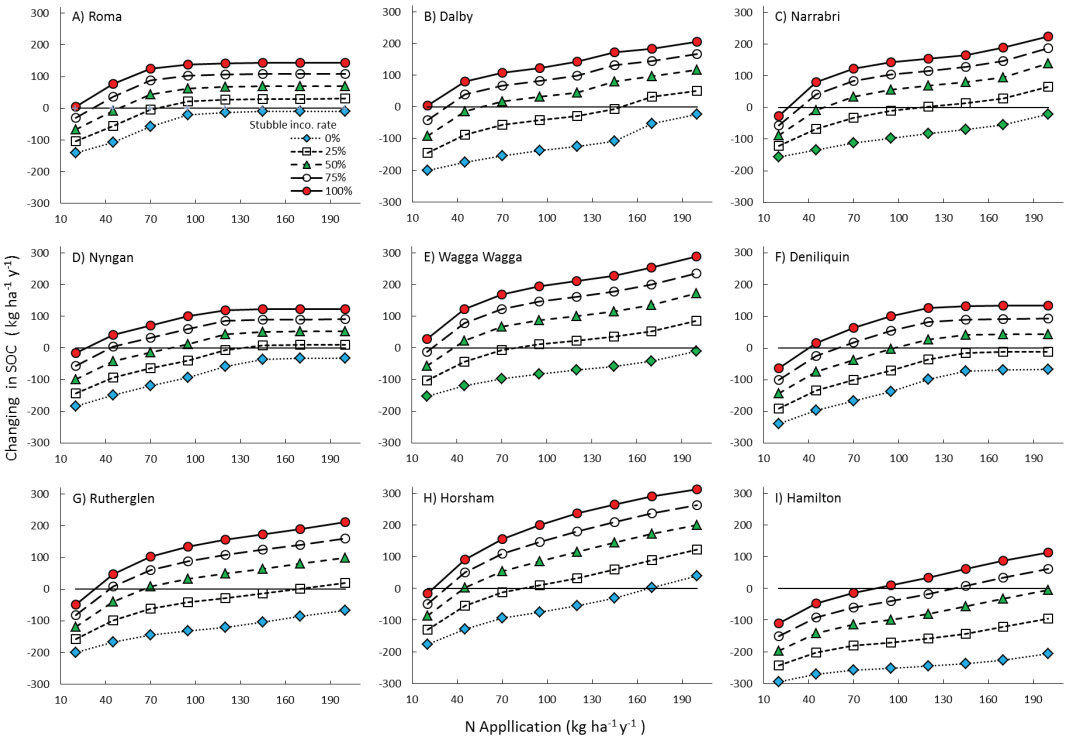

Figure 1. Change in SOC under continuous wheat cropping showing the impact of nitrogen fertilisation rates and various proportion of stubble incorporation over 60 years in eastern Australia.

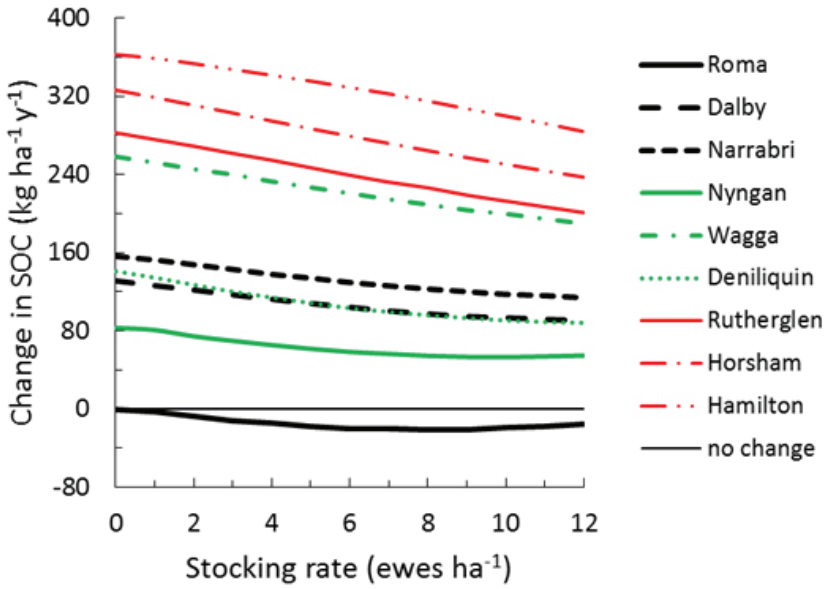

Figure 2. Changes in soil organic carbon under continuous grazing showing the impact of stocking rates over 60 years in eastern Australia.

Under a range of farming management practices, SOC changes under the crop-pasture rotation varied from northern to southern sites (Figure 3). At Roma and Nyngan, the range of SOC changes was much narrower than at other sites. As the lowest change in SOC occurs at the hottest site (Roma) and the second driest site (Nyngan), it appears the temperature and rainfall play an important role that drives the dynamics of SOC with the interactions of farm management. In general, longer periods of pasture in the rotation resulted in more SOC sequestration at the southern sites, but not at the northern sites where increases in the pasture phrase result in less increase in SOC.

Increasing the length of the pasture phase is believed to favour increasing SOC. Our analyses show this to be the case at the southern sites (Rutherglen, Horsham and Hamilton, but not at the northern sites (Roma,

Dalby, Narrabri and Nyngan). There was virtually no change seen at Wagga Wagga or Deniliquin by lengthening the pasture phase from 4 to 8 years in a 12 year rotation with crops (Figure 3). However, the effect of stubble incorporation and nitrogen fertiliser was largest under the 4 years of pasture compared to 8 years of pasture because the length of time in cropping was longer. The negative effects of stocking rate can be largely overcome with a period of cropping containing a high level of stubble incorporation and nitrogen fertilisation.

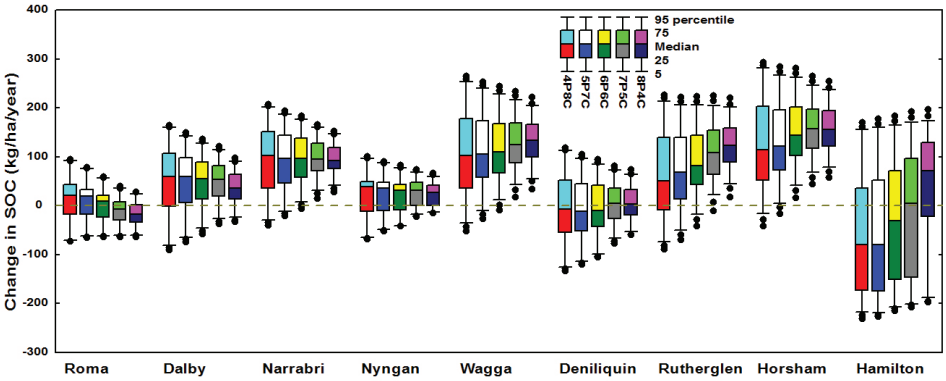

Figure 3. Change in SOC under the range of stubble incorporation, N application and stocking rate with different years of pasture in the cropping pasture rotations over 60 years in eastern Australia.

Our analyses considered a generalised, but typical, pasture and cropping regime of eastern Australia to explore the extent that SOC can be increased through some farm management options. Because farm economics drive management decisions, the value of SOC at present (e.g. A$23/t C in 2015 in Australia) is too low to affect any rational farm management option to raise SOC. The full potential of raising SOC is yet to be realised but this study suggests it is biologically feasible. It was found that the higher the site mean annual rainfall, the greater the potential to increase SOC in grazed pasture or crop-pasture rotation systems, however, high temperature reduced gains in SOC, with an apparent optimal mean temperature at which the highest SOC increase can be obtained (data not shown).

Acknowledgements

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Subsoil manuring in the high rainfall zone: a practice for ameliorating subsoils for improved productivity

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Abstract
The practice of subsoil manuring (SSM) is now transitioning into its next phase of practice change in the high rainfall zone (HRZ) of Southern Australia. It is a practice that involves the placement of large volumes (10-20 t ha^{-1}) of nitrogen rich organic manures within the dense (soil bulk density of 1.4 g cm^{-3} or higher) clay matrix of subsoils. These soils generally have low macro-porosity (around 5%) and are often sodic (generally higher than 10% exchangeable sodium) and are therefore dispersive. The practice, over time, leads to the breakdown of the heavy structural units of soil into smaller aggregates. The process appears to be driven by soil microbial activity assisted by root-soil-microbial interactions. Work conducted since 2003 has generated the evidence that this practice has the potential to almost double the grain yields (42%-96% across sites and seasons) in the HRZ (550 to 750 mm) of Southern Australia through the creation of extra plant available water capacity (PAWC) in these hostile clay subsoils. The capture, storage and use of extra water more efficiently has been the key to productivity gains through this practice in a region where soil water deficit during grain filling has been a frequent phenomenon.

Key words
Water use efficiency, bucket size, summer fallow efficiency, sodic soil, clay aggregation

Introduction
Farmers in the HRZ had made an initial step change in productivity through raised beds under conditions of severe water logging during the long, cool growing season (Peries et.al., 2004). The practice of SSM, with the potential for the next step change evolved from research and development undertaken to ameliorate dense, sodic-clay subsoils in Southern Victoria (Gill *et.al*., 2009). While raised beds led to limited increases in PAWC in the subsoil (Peries *et.al*., 2010), it was hypothesised that further increases were possible if the dense clays were ameliorated with Nitrogen rich composted organic matter. This material placed within the clay matrix in a single deep ripping operation would eventually lead to the aggregation of the otherwise dense, hostile clay structural units. This would result in an irreversible increase in the PAWC ('bucket size') to help crops overcome the soil water limitations frequently experienced during grain fill (Wong and Asseng, 2007).

Methods
The practice of SSM involves the placement of high volumes of Nitrogen rich organic material such as composted poultry litter (up to 20 t ha^{-1} fresh weight with 20% moisture) at depth (30-50 cm) within the clay matrix during a deep ripping operation that is also expected to create some shattering of the subsoil when carried out under appropriate soil moisture conditions. The nutrient content in the composted poultry manure can be variable , but on average, the material used in our trials had 3.8% N, 1.9% P and 2.2% K, wth a C:N ratio of around 10-14:1. The rip lines are spaced between 80 cm and 100 cm apart. Between 2005 and 2012 a large number of trials have looked at the benefits of this practice across different soils and rainfall regimes in high rainfall Southern Victoria and South Australia. Grower interest has also resulted in these trials being designed with additional treatments to (a) partition the effect of nutrients from that of organic matter, (b) study the effects of surface application of similar rates of organic matter without soil disturbance and (c) look at incorporation with less aggressive soil disturbance such as with a mould board plough. The technology has now advanced more than ten years since it was first proposed.

The early trials compared the control with (a) deep ripping only, (b) deep ripping with 10 and 20 t ha^{-1} composted poultry manure, (c) deep ripping with inorganic nutrients only, to match the nutrients in 20 t ha^{-1} manure and (d) deep ripping with 10 t ha^{-1} poultry manure and the balance in inorganic nutrients to match the 20 t ha^{-1} manure.

Results and Discussion

A simple comparison of the results from cereals grown in the SSM trials (Table 1) shows that between 2005 and 2012, an average yield increase of 63% (range 42%-96%) was obtained across sites and seasons. Very early results (Gill *et.al*., 2008; 2012) indicated that the success of the practice in delivering improved productivity was the result of capture, storage at depth and use of extra amounts of soil water from in-crop rain or pre-crop summer fallow. The effect was most pronounced when there was a spring cut-off (terminal drought, such as in 2009 when the treated (SSM) crops had an extended leaf area duration of between 10 and 14 days (data not discussed here). Where there is improved summer fallow efficiency (Gill *et. Al*., 2012), the deep soil water is likely to be utilised at a higher water use efficiency (Kirkegaard et.al., 2007; Gill et.al., 2008) and the deep storage is likely to be facilitated by the aggregation of the otherwise hostile clay (Figure 1) through the interaction between the organic substrate, the proliferating root mass and the root exudates reacting to modify the clay matrix (Clark *et.al*., 2007; Gill et.al., 2009). The changes to the clay structures are expected to be permanent, with participatory action research trials suggesting incremental benefits up to six years or more, from a single episode of SSM.

Table 1. Summary of crop yields for commercial and subsoil-manured cereal crops, at sites across Victoria, from 2005-2012. (*Crop 1, 2 etc. refer to the season of cropping since SSM was carried out on the trial as a once-off practice*) (after Sale et.al., 2015).

Year	Site	Crop	Grain Yield (t/ha)			Increase (%)
			Commercial crop	Subsoil manured [1]	Increase in yield	
2005	Ballan	Wheat (1st crop)	7.6	12.5	5.3	70 %
2006	Ballan	Wheat (2nd crop)	3.6	5.6	2.0	55 %
2009	Derrinallum	Wheat (1st crop)	5.0	9.8	4.8	96 %
2009	Penshurst	Wheat (1st crop)	4.8	7.6	2.8	58 %
2009	Winchelsea	Barley (1st crop)	4.4	7.7	3.4	77 %
2010	Wickliffe	Wheat (1st crop)	9.1	11.6	2.5	27 %
2011	Derrinallum	Wheat (3rd crop)	5.0	7.4	2.4	48 %
2011	Stewarton	Wheat (1st crop)	5.7	8.1	2.4	42 %
2012	Derrinallum	Wheat (4th crop)	6.3	10.4	4.1	65 %
2012	Stewarton	Wheat (2nd crop)	4.9	9.4	4.5	92 %
2012	Dookie	Wheat (2nd crop)	5.3	9.4	4.1	77 %
		Average for cereals	**5.6**	**9.0**	**3.5**	**63 %**

[1] Subsoil manured plots received 20 t ha^{-1} (fresh weight) of an N-rich organic amendment (less than 20% moisture content) which was incorporated in rip-lines, 80-83 cm apart, at a depth of 30-40 cm in the subsoil.

Figure 1. Change in the appearance of the subsoil at 30-40 cm depth, sampled 4 years after subsoil manuring was carried out. Untreated subsoil on the left, treated on the right.

In 2012, a trial was also established at the Southern Farming Systems research site at Westmere, in the HRZ on a grey sodosol soil (Isbell, 1996), where amongst a range of treatments we tried to partition the effects of nutrition from that of organic manures and also tested the effect of a less aggressive incorporation of the manure through the use of a mould board plough alongside other treatments that also included the surface

application of manure without incorporation. In all treatments where manure or nutrients were placed in the subsurface, the soil was ripped to 40 cm using a two-tine deep ripper, with tines placed 83 cm apart.

Table 2. Results of the Westmere subsoil manuring trial comparing twelve treatments involving tillage/ripping, nutrients and manure.

Treatment	Gr. Yld. (t ha^{-1})	Heads (m^{-2})	Grains/ head	Gr.wt. (mg)	Spikelet Length (cm)	Grain Protein (%)
1. No till, no nutrients	5.0	270	44.8	41.2	9.1	9.6
2. No till, artificial nutrients	5.0	253	44.4	43.5	9.5	9.6
3. No till, manure	6.4	262	52.2	47.2	10.6	12.1
4. Ripped deep, no nutrients	4.8	257	48.7	38.3	9.6	10.3
5. Ripped deep, artificial nutrients	4.4	254	43.5	40.1	8.9	9.9
6. Ripped deep, manured	7.9	337	49.0	47.1	9.8	13.3
7. Ripped, surface, no nutrients	5.4	261	51.8	39.9	10.4	9.4
8. Ripped, surface, artificial nutrients	5.8	280	47.5	43.5	9.8	10.0
9. Ripped, surface, manure	6.1	280	50.2	43.4	9.5	13.0
10. Mouldboard, no nutrients	5.5	276	49.7	40.0	10.2	10.2
11. Mouldboard, artificial nutrients	4.9	306	41.8	39.9	10.8	10.7
12. Mouldboard, manure	5.1	283	45.6	39.4	9.5	12.8
lsd	1.1	44.4	7.8	5.2	1.2	1.02
Fprob	0.02	0.02	0.183	0.008	0.05	0.23

Where a mould board was used, the material was placed on the surface prior to incorporation. Table 2 shows yield results from this trial in the first year of SSM. The results indicate the positive effect of placing manure at depth (T6): an effect that is not necessarily related to nutrition alone or ripping alone. Crop water use was also monitored in this trial using a neutron moisture meter and it was observed that at depth 20-100 cm in the profile, more soil water (91 mm) was used by the SSM treatment (T6) compared to deep ripped with inorganic nutrients only (69 mm-treatment T5) or treatment 2 with artificial nutrients and no tillage/ripping (53 mm) (details not discussed here). There are strong indications that subsoil manuring is a sustainable practice with a potential to significantly enhance productivity through improved water use efficiency in the Victorian HRZ. It also presents itself as a practice with an adaptive potential to a warming and drying climate.

Conclusion

Participatory action research (PAR) is currently being undertaken around Victoria, South Australia, Southern NSW and Tasmania in the search for alternative amendments for SSM compared to those such as Lucerne pellets (2005-2007) and composted poultry manure (2009- 2014) that were used in early research trials. Work is also in progress to fine tune the recommendations on SSM, on appropriate rates of application based on soil type and rainfall. Over fifty SSM trials have been established in the last three years using a prototype machine developed for the purpose over the years, and are being monitored around Southern Australia to evaluate the effectiveness of the practice. Demonstration trials have been extended to the drier parts of Victoria to assess the effectiveness of the practice under conditions different to those in the HRZ. One paddock scale subsoiling machine became available in 2012 and several smaller versions are in production simply through interest generated amongst the farming community. Farmers are innovators and their involvement has seen an accelerated adoption focus in the last two years.

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Crop productivity and profitability improved by high analysis granular P over liquid P or rock phosphate.

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Abstract
Due to the combination of low production years and highly volatile fertiliser prices many growers in central NSW have started to explore the use of alternative phosphorus fertiliser sources and nutritional programmes. Traditionally growers have applied all their high-analysis phosphate fertiliser with seed at the time of sowing. The aim of this experiment was to evaluate the effectiveness, profitability and residual benefit of various phosphate fertiliser sources including high-analysis granular P (MAP), liquid P (polyphosphate and phosphoric acid) and rock phosphate. These phosphorus fertiliser products were applied at 0 kg P/ha, 5 kg P/ha, 10 kg P/ha and 20 kg P/ha over the same area for three consecutive winter crop seasons, 2009-2011. In the fourth season (2012) no P was applied, with grain yield response to residual P evaluated. Except for 2009 (severe moisture stress during flowering and grain fill), grain yield responded positively with increasing application rates of high-analysis granular P, and both forms of liquid P. However high-analysis granular P was significantly more profitable due to lower cost per kg of P. There was no significant grain yield benefit from the application of rock phosphate when averaged across the four years. Grain yield in 2012 responded positively to residual phosphorus to all P products except rock phosphate.

Key words
Phosphate fertiliser, high-analysis granular, liquid P fertiliser, biological fertiliser and rock phosphate.

Introduction
In southern NSW growers have traditionally banded all their high-analysis granular fertiliser at sowing with fungicide treated seed. It is generally accepted that approximately 20-30% of fertiliser P banded at sowing is available in the first year and the residual amount available in subsequent crops (Price, 2006). The exact ratio of how much P gets locked up will vary depending on soil characteristics such as soil texture, soil acidity/alkalinity and availability of aluminium, iron and calcium. The potential of a soil to lock up P is estimated by the phosphorus buffer index (PBI). The majority of soil types within southern NSW have low PBI values indicating that much of the applied P will become plant available over time. The combination of paddock history, crop type (root morphology and arbuscular mycorrhizal fungi), sowing date (early or late sown) and soil test results have proven to be beneficial tools in predicting individual paddock responsiveness to freshly applied fertiliser P.

Growers and advisers are now being challenged by a new hypothesis which claims further fertiliser efficiencies can be gained for southern NSW. Some biological advocates promote the use of rock phosphate products in conjunction with microbe-friendly seed treatments and biological inoculants. It is claimed that the improved biological health of the soil will unlock some of the tied-up P and enhance the effectiveness of applied P fertiliser. Conventional understanding of rock phosphate suggests it is only appropriate for slow growing grass or tree crops and only successful on acidic soils with high rainfall (Bolland 2007).

Interest in liquid P fertilisers is also developing due to the increased efficiencies of liquid P over granular P on the alkaline calcareous soils of South Australia (McBeath, 2005). These efficiencies are yet to be proven in the common soil types of southern NSW as the presence of topsoil lime is not considered regionally significant. The aim of this experiment is to evaluate the effectiveness, profitability and residual benefit of various phosphate fertiliser sources over a 4 year period.

Methods
From 2009 to 2011 a range of phosphorus fertilisers products (Table 1) were applied over the same plot (1.8 m x 20 m) for three consecutive winter crop seasons. The fourth season (2012) relied on residual P with no fertiliser P applied. Phosphorus fertiliser rates included 0, 5, 10 and 20 kg P/ha. The trial site was located 35

km north-west of Forbes, central NSW. The trial design was a randomised complete block (4 replicates) and laid out as a single row. A basal application of nitrogen as urea was applied to balance all treatments.

Table 1: Fertiliser source/product details

Phosphorus source	%P	$/tonne	$/kg P
High-analysis - MAP (granular)	22	$950	$4.32
Rock phosphate (granular)	12	$775	$6.46
Phosphoric acid - Ezy NP (liquid)	16	$2,231	$13.94
Polyphosphate - Polyphos (liquid)	23	$3,214	$13.98

* Fertiliser costs derived from 2009 prices.

An additional systems trial was conducted to evaluate the impact of microbe-friendly seed treatments and biological inoculants to rock phosphate fertiliser. The additional inoculants included a broad spectrum inoculum of compost microbes applied to both the seed and applied as a foliar spray at mid-booting (GS45). The seed was not treated with fungicide seed dressing (ie Raxil®) as in accordance with the recommendations from the rock phosphate supplier.

Table 2: Trial site details 2009

Soil type	Grey vertosol	**Total P**	252 mg/kg	**PBI**	106 mg/kg	**pH_{Ca}**	7.6
Colwell P	15 mg/kg	**Organic P**	190 mg/kg	**In-organic P**	62 mg/kg	**Free lime**	1-5%

* Soil test results derived from 0-10 cm depth

Table 3: Monthly rainfall (mm) from 2009 to 2012.

Month	Rainfall (mm)												Stored	In-crop
	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	PAW [a]	rainfall
2009	14	37	38	60	5	83	30	10	13	13	20	75	84	154
2010	10	163	42	49	45	32	58	47	50	67	85	98	140	300
2011	8	70	83	25	34	12	17	57	23	56	139	102	202	199
2012	35	179	128	37	60	44	43	15	33	7	18	14	147	203

Results

Table 4: Predicted grain yield (kg/ha) and relative yield (%) across individual site years and average grain yield across 3 years (2009-2011).

Product	Rate (kgP/ha)	2009 Wheat		2010 Wheat		2011 Canola		2012 Wheat (No P applied)		Predicted average grain yield over 3 years (2009-2011)	
		kg/ha	RY%	kg/ha	RY%	kg/ha	RY%	kg/ha	RY%	kg/ha	RY%
Nil	0	1652	96	4153	82	1378	58	4224	88	2415	81
MAP (granular)	5	1434	83	4564	90	2027	86	4570	95	2691	90
	10	1520	88	4723	93	2175	92	4536	95	2831	95
	20	1504	87	5058	100	2368	100	4798	100	2993	100
Rock phosphate (granular)	5	1533	89	3991	79	1557	66	4149	86	2362	79
	10	1637	95	4093	81	1726	73	4314	90	2506	84
	20	1576	91	4165	82	1872	79	4213	88	2539	85
Phosphoric acid (liquid)	5	1681	98	4333	86	2041	86	4200	88	2689	90
	10	1608	93	4598	91	2304	97	4323	90	2847	95
	20	1551	90	4851	96	2346	99	4628	96	2925	98
Polyphosphate (liquid)	5	1724	100	4579	91	2195	93	4337	90	2834	95
	10	1667	97	4750	94	2315	98	4612	96	2925	98
	20	1518	88	4785	95	2323	98	4582	95	2879	96
LSD (P=0.05)		317.3		397.7		289.1		250.4		198	

*Predicted average grain yield over 3 years includes both wheat and canola yields

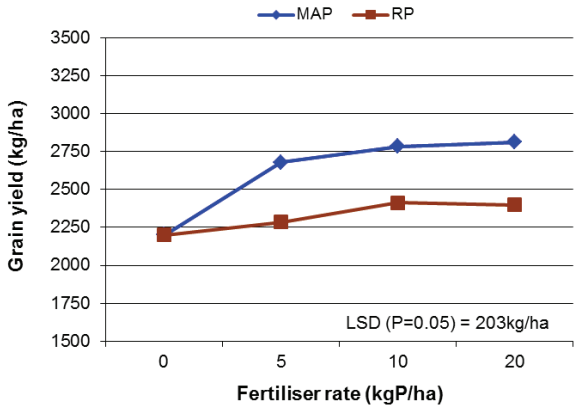

Figure 1: Average grain yield response over a three year period (2009-2011) comparing MAP to Rock phosphate + biological inoculants.

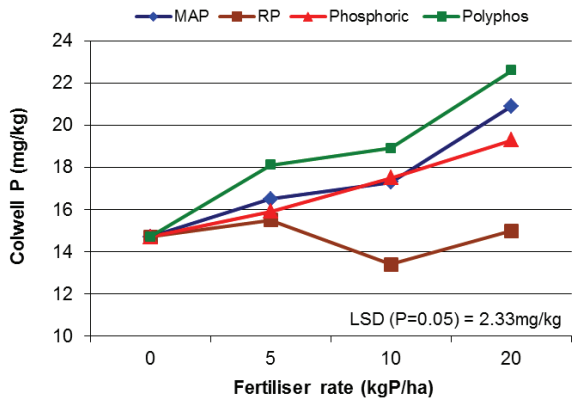

Figure 2: Residual soil phosphorus (2011) after the first two wheat crops (2009 – 2010).

Table 5: Gross margin ($/ha) across individual site years and the gross margin benefit ($/ha) of fertiliser treatments over the nil P treatment over 4 years (2009-2012).

Fertiliser source	Rate (kgP/ha)	Gross margin ($/ha)					$/ha bennefit over the Nil P
		2009	2010	2011	2012	Total	
Nil P	0	$90	$591	$319	$732	$1,732	
MAP	5	$25	$651	$622	$811	$2,109	$378
	10	$21	$661	$674	$803	$2,160	$428
	20	-$26	$685	$728	$864	$2,251	$519
Rock phosphate	5	$34	$526	$376	$714	$1,651	-$81
	10	$23	$514	$428	$752	$1,717	-$14
	20	-$54	$464	$437	$729	$1,576	-$156
Phosphoric acid	5	$27	$557	$581	$726	$1,890	$159
	10	-$58	$540	$643	$754	$1,879	$148
	20	-$209	$451	$524	$824	$1,591	-$140
Polyphosphate	5	$35	$606	$658	$758	$2,057	$325
	10	-$46	$571	$648	$821	$1,993	$262
	20	-$215	$438	$513	$814	$1,550	-$182
Grain price received ($/ha)		$200	$200	$500	$230		
Variable costs ($/ha)		$240	$240	$370	$240		

*Refer to Table 1 for various P fertiliser costs

Grain yield response

On average, grain yield was significantly affected by fertiliser source (P<0.001) and rate (P=0.001). The average grain yield over all treatments for the 3 year period was 2.73 t/ha. The highest average yield was achieved with MAP at 20 kg P/ha at 3t/ha (Table 4). Grain yield responded positively with increasing application of MAP and both forms of liquid (phosphoric acid and Polyphos). For example the MAP fertiliser treatment at 5, 10 and 20 kg P/ha increased grain yield on average by 276 kg/ha, 416 kg/ha and 578 kg/ha respectively.

Averaged across three years there was no significant yield benefit from rock phosphate fertiliser, however in one season alone (2011) the 10 and 20 kg P/ha rate did produce a significant yield benefit of 348 kg/ha and 494 kg/ha over the nil P treatment (Table 4). This grain yield benefit was not carried over into the final year (2012). The addition of biological inoculants did not improve rock phosphate response greater than MAP in this trial (Figure 1).

Residual P benefit

Residual P benefit was measured via soil testing after the 2010 wheat crop (Figure 2) and measuring grain yield in 2012 (Table 4), the year when no P fertiliser was applied to the wheat crop.

Residual soil (Colwell P) levels ranged from 14.7 mg/kg to 22.7 mg/kg and differed significantly with fertiliser source (P<0.001), rate (P<0.001) and interaction between fertiliser source and rate (P=0.02). The greatest residual benefit was from the high P rate (20 kg P/ha) of Polyphos and MAP, with a respective increase of 7.9 mg/kg and 6.2 mg/kg over the nil P treatment (Figure 2). Residual P levels following MAP application increased as the rate increased. The 5 kg P/ha, 10 kg P/ha and 20 kg P/ha increased levels by 1.8 mg/kg, 2.6 mg/kg and 6.2 mg/kg respectively. Rock phosphate did not increase soil P levels despite having lower grain yield. Both liquids (Phosphoric acid and Polyphos) had similar residual P compared to the MAP treatment. However, Polyphos (20 kg P/ha) did have a significant (P<0.001) residual benefit of 3.3 mg/kg over the 20 kgP/ha phosphoric acid treatment (Figure 2).

Grain yield (2012) benefit from residual P was significantly affected by the previous three seasons (2009-2011), fertiliser source (P<0.001) and rate (P<0.001). The 5, 10 and 20 kg/ha P rates of MAP produced a yield benefit of 346 kg/ha, 312 kg/ha and 574 kg/ha respectively over nil P treatment. There was no significant yield benefit above nil P in 2012 where rock phosphate had been applied in the previous three seasons. Both liquid products produced similar yield response to MAP fertiliser. However, phosphoric acid applied at 5 kg P/ha did produce a lower yield of 370 kg/ha when compared to MAP at 5 kg P/ha.

Profitability

Cost ($/kg P) of the various fertiliser sources were $4.32/kg P for MAP, $6.46/kg P for rock phosphate, $13.94/kg P for phosphoric acid and $13.98/kg P for Polyphos (Table 1). The most profitable treatment over the four year period was 20 kg P/ha of MAP, with a total benefit of $519/ha over the nil P treatment (Table 5).MAP produced a positive monetary return across all three rates and grain yield increased as fertiliser rate increased. The 5, 10 and 20 kg/ha P rates increased profitability (over four years) by $378/ha, $428/ha and $519/ha respectively. Rock phosphate treatments produced a negative monetary return across all three rates. The 5 kg P/ha, 10 kg P/ha and 20 kg P/ha rate reduced profitability by -$81/ha, -$14/ha and -$156/ha respectively. It was more profitable to apply no fertiliser than apply rock phosphate. Both forms of liquid phosphate (Phosphoric and Polyphos) produced a positive monetary return at the lower rates of 5 kg P/ha and 10 kg P/ha and negative monetary return at the higher rate of 20 kg P/ha (-$140/ha and-$182/ha respectively). These results do not consider the additional cost associated to convert machinery for liquid P application, or the additional freight cost required for less concentrated P sources.

Conclusion

These results highlight the importance of selecting a phosphate fertiliser source that is both cheap and effective. Growers and advisers must consider cost per kg of P compared to cost per tonne of product, as this greatly influenced profitability in this trial. High-analysis granular (MAP) and both forms of liquid P had similar responses; however MAP was significantly more profitable due to a lower cost per unit of P.

Fertiliser needs to become plant available to become effective. These results indicate that high-analysis granular fertiliser and both forms of liquid P respond positively and similarly, whilst rock phosphate did not produce a response, presumably due to its very low availability for plant uptake. Therefore rock phosphate fertiliser was both ineffective and expensive in the four years that it was evaluated in this trial. The addition of biological inoculants did not improve rock phosphate response to the point of equalling MAP in this trial.

Fertiliser source and rate will impact on both the current season as well as future years. Residual P benefit will decline if fertiliser rates are reduced to allow for more expensive forms of P to be used (i.e. liquids). If crop removal of P is greater than fertiliser P input, soil P will decline until crop P removal is equal to the rate of mineralisation of organic P. Selecting the appropriate fertiliser source will allow yield to be maximised when seasons allow, and reduce risk when seasonal factors produce low yields.

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Why do farmers partially adopt conservation farming practices? A sociological study of stubble retention in NSW and Victoria

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Abstract
Despite considerable investment in Australia and abroad to promote the benefits of conservation farming, rates of on-farm adoption in some regions have been slower than expected. Recent research suggests that this may be due to the preference by farmers for partial adoption of conservation farming practices. However, such research provides limited insights into why farmers may prefer partial adoption. This paper aims to address this issue by drawing upon qualitative data from a DAFF-funded project exploring stubble retention practices by grain growers in NSW and Victoria. Our study reveals that while growers recogni=se the significant benefits in retaining crop stubbles, there exist a range of constraints in moving towards full stubble retention. Growers seek to reconcile these benefits and constraints through partial adoption. They continue to selectively and reluctantly burn stubble as they recognise that moving towards full stubble retention would undermine their flexibility to manage biophysical and financial variability. This finding suggests that improving the uptake of stubble retention requires greater accommodation of growers' existing practices, as well as recognition that selective burning may be complementary to growers retaining crop stubbles.

Keywords
Conservation farming; social research; partial adoption; relative advantage; stubble retention; trialability

Introduction
Conservation farming, including no till, conservation tillage and retaining crop stubble, is increasingly encouraged by government and farming organisations as an alternative to stubble burning. The benefits of conservation farming are well-known and include: retaining and improving soil carbon, avoiding the loss of nutrients from burning, improved plant biomass, and healthier and more productive crops (Scott *et al*., 2010). Yet, despite considerable investment in Australia and abroad to promote the benefits of conservation farming, rates of on-farm adoption in some regions – such as those with higher rainfall in parts of Victoria and Southern NSW – have been slower than expected (D'Emden *et al*., 2008, Grabowski and Kerr, 2014, Lal, 2007, Llewellyn *et al*., 2012). Research to date seeking to explain the slow adoption rates has focused primarily on the obstacles faced by farmers in adopting conservation farming practices (McRobert and Rickards, 2010). These may include capital and labour constraints, increased costs associated with the need to upgrade machinery, lack of observed benefits, and problems with weed control. In much of this work, adoption is measured as a binary distinction where the farmer is classified as either an adopter or non-adopter (e.g., Davey and Furtan, 2008, D'Emden *et al*., 2008, Knowler and Bradshaw, 2007). More recently, scholars have recognised that the adoption of conservation farming practices is an ongoing and complex process characterised by incomplete or partial adoption. From this perspective, farmers may adopt some practices, but 'maintain a degree of flexibility in their approach to soil disturbance and respond to economic and seasonal drivers' (Llewellyn *et al*., 2012: 204). Indeed, recent research argues that the key to successful no-till farming is greater flexibility in farming practices, such as the introduction of strategic tillage (Dixon, 2014). While drawing attention to the complexity of adoption processes, and particularly the significance of partial adoption, this research provides limited insights into why some farmers may prefer partial adoption of specific conservation farming practices. The aim of this paper is to address this issue. Drawing upon qualitative social research into stubble retention by grain growers in NSW and Victoria, we investigate why farmers do not adopt full stubble retention, despite recognising the soil benefits.

Explaining partial adoption

In a seminal synthesis of the adoption literature, Pannell et al (2006) argue that there are two key issues that shape farmers' decisions whether or not to adopt conservation and environmentally-oriented practices. The first is *relative advantage*, which refers to the extent to which an innovation/practice is better than that which it supersedes: this is shaped by 'a range of economic, social and environmental factors' and depends specifically 'on the landholders' unique set of goals and the biophysical, economic and social context where the innovation will be used' (Pannell et al., 2006). The second feature is *trialability*, which is basically the extent to which an innovation/practice can be trialled on-farm, and the various factors – economic, social and environmental – that shape what a farmer can realistically learn from the trialling process. Trialling is vitally important, since it 'allows the landholder to avoid the risk of large financial costs if the practice turns out to be uneconomic or fails due to inexperience' (Pannell et al., 2006). While the concepts of relative advantage and trialability have been applied previously to understand the obstacles to farmers' conversion to no-till farming (McRobert and Rickards, 2010), they are yet to be applied systematically to make sense of (a) why farmers might not fully adopt stubble retention, and (b) the consequences for stubble management practices. We address these issues in the remainder of this paper.

Methods

The research reported in this paper forms part of a broader project funded by the Commonwealth Department of Agriculture. The project aimed to trial on-farm stubble and soil nutrient practices to increase carbon stored in soil in broadacre cropping regions of southern, central NSW and Victorian dryland and irrigated areas. Social research was a crucial dimension of the project. Qualitative research methods – comprising group and individual interviews – were used to assess growers' knowledge, understanding and practices of stubble management. Group interviews were conducted with a sample of 6-14 landholders from each of the six grower groups involved in the broader project. Individual semi-structured interviews with two growers from each group enabled more detailed exploration of, as well as insights into, stubble management practices. All interview s were transcribed for analysis and initially analysed using principles of grounded theory. That is, open coding was firstly conducted to find common descriptors, followed by a second cycle of axial coding which sought to develop connections and relationships between codes (Miles and Huberman, 1994). Axial coding enabled us to develop contexts around particular code labels that emerged through open coding, which were essential for us to interpret participant reports. Finally, the data were analysed using a thematic analysis by exploring patterns across the data.

Relative advantage: burning vs stubble retention

Most participants recognised the need to reduce burning of stubble and to increase stubble retention on their property. Motivations to do so were related mainly to personal goals and values around burning and/or tilling. For example:

> I think farmers are coming to the conclusion themselves. That, you know got sick of the dust and the dust problems and can see there's moisture benefits. (Farmlink, Group interview)

> Yeah I've been trying to do that [retain stubble] all my life … we've made some big mistakes…. There's been a goal of my life I didn't like burning. (Rural Management Strategies, Grower B)

Pragmatic/business reasons were also viewed as important. In the following cases, retaining stubble was viewed as being less costly than burning.

> …it was a business decision for us [to retain stubble]. That was basically the main reason … it just worked for us, you know. Not as much labour around, small family farm and the opportunity was there to develop it. (Central West Farming Systems, Group interview)

> There's a lot of cost in burning today. Like, it's something that really if you could stop doing it tomorrow you would. (Holbrook Landcare Network, Group interview)

A number of growers believed that retaining stubble had benefits over burning in terms of retaining soil nutrients and moisture.

> The soil needs to be improved and you go on burning it, where's all the organic matter, you only get a bit out of the root system that's left after you burn it; and it depends how hot the burn is, how much is left. Whereas if you can avoid burning it a bit, even if you've got to do a little bit more work, I think that's better. (Holbrook Landcare Network, Grower B)

> You retain a lot more soil moisture at the surface by keeping that cover…. I mean we just didn't see value in burning. (Southern Farming Systems, Grower B)

A key theme that emerged from the data was the growing incompatibility of previous practices, namely burning of stubble, with personal beliefs and values as well as with farm profitability. This had an important influence on growers' views on the benefits of adopting stubble retention practices. Thus, reduced labour intensity as well as improved soils and soil moisture emerged as the most significant reported benefits of retaining stubble. For example:

> I reckon it's less labour intensive like 'cause you can sort of put one bloke on a sprayer and it keeps your paddock clean all summer to having someone sort of ploughing and boarding and all that sort of stuff…. You burn less diesel. (Rice Research Australia, Group interview)

> …I think [stubble retention] keeps more in the soil and just ground cover, moisture infiltration. When it's bare, particularly this Mallee country can blow and all that sort of stuff…. I'd just like to try and get more humus in the soil, just make it softer sort of thing. (Central West Farming Systems, Grower A)

Negative experiences from trialling stubble retention

Despite the relative advantages reported in retaining stubble, growers across the group and individual interviews reported numerous challenges in implementing stubble retention in practice. This created problems in moving towards full adoption of stubble retention. The most significant of these were the impact of pests, diseases and weeds where stubble is retained. For example:

> There's probably, in most cases there's advantages to burning it. There's problems when you keep it, there are pests that you've got ... weed management is hard when you keep it. (Farmlink, Group interview)

> We have too many diseases, like our leaf spotting in wheat, to retain our stubbles [after the end of March] … so we are stubble burners…. Our burns are coolish, but the risk from pests and diseases from sowing into stubbles here is too high for me to take. (Holbrook Landcare Network, Grower A)

Biophysical constraints, such as being in a high rainfall zone, and higher costs, were mentioned also as important limitations influencing growers' capacity to move towards full stubble retention.

> In this valley, in here where it's high rainfall, heavier soils and heavier trash management generally speaking with traditionally up until now narrow growth spacings, a lot of that work [stubble retention] is very hard to implement. (Holbrook Landcare Network, Group interview)

> I don't think people who don't make a profit can really do stubble [retention]…. The nitrogen tie up for the first few years is just horrendous. The bills of urea, ...truckloads of urea that come through the gate here, really all we're doing is feeding the breakdown of organic matter until it starts giving back to us. (Rice Research Australia, Grower A)

While not usually associated in the literature with the trialability of a technology/practice, our research found that technological/technical constraints represented a major challenge for growers in incorporating stubble prior to sowing. For example:

> You're really restricted by the implements that you have and your row spacing and whether it's a tyned implement or a disc implement. (Rice Research Australia, Group interview)

> A lot of machinery can't handle [stubble], it can't (Southern Farming Systems, Group interview).

For a number of growers, moving towards full stubble retention required upgrading of machinery, a costly option especially for growers with mixed farming enterprises where grain is not the predominant commodity in their farming operation.

The relative advantages of selective stubble burning

As a consequence of the challenges in implementing stubble retention, many growers continue to selectively burn stubble. In these circumstances, burning is a crucial back-up option, which is used reluctantly to minimise risk and improve growers' flexibility to deal with seasonal variations in stubble loads. For instance:

> …the cool burn we do in the autumn is probably as much as I'd like to do. In the cereals I don't burn anything … I mean basically if you can't get through it and you can't do anything else with it and bale it or do something else with it, you have to burn it, that's what you have to do. (Rice Research Australia, Grower B)

> I mean traditionally [growers in the district] probably did use fire but maybe they're not using fire as much as what they used to. But if they're going to, it's in those big years when fire is needed to … physically break them [stubbles] down in that short period of time. (Central West Farming Systems, Grower B)

Burning is also critical for some farmers in improving weed management as the following quotes illustrate:

> At the end of the day we've got to make money and if it means burning the stubble once every now and again to get that crop, to get the chemicals to work, to have that crop a better crop, well we can do it. (Rural Management Strategies, Group interview)
>
> Burning does a good job for Trifluralin and that sort of thing but I'm still not convinced it's the right way to go about it. (Southern Farming Systems, Grower B)

Conclusions

This paper has argued that personal, biophysical and cost-related motivations are more important to grain growers than external pressures (such as regulation or community pressure) in making decisions on cutting back of burning and increasing stubble retention. Growers have a high level of awareness of the economic and environmental benefits associated with stubble retention. However, there exist a range of reported technical, biophysical, biological and cost challenges and constraints that contribute to problems in achieving these benefits. These are consistent with those reported in the existing conservation farming literature. Nevertheless, unlike previous studies that treat such challenges as obstacles to adoption, our study reveals that many growers are willing to trial stubble retention. Stubble retention is *partially adopted* because of the negative experiences in trialling/implementation as well as the recognition that moving towards full stubble retention would undermine growers' flexibility to manage biophysical and financial variability. Flexibility is crucial for some farmers in enhancing trialability (McRobert and Rickards, 2010). Recent Australian research emphasises the importance of flexibility – such as the introduction of strategic tillage – in improving the success of no-till farming (Dixon, 2014). In our study, it is selective burning of stubble that provides growers with flexibility in their stubble management practices, and, given the reported benefits, may be important in giving growers additional confidence in continuing to engage in stubble retention. This finding suggests that improving the uptake of stubble retention requires greater accommodation of growers' existing practices, as well as recognition that selective burning may be complementary to growers retaining crop stubbles.

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Quantifying the effect of soil organic carbon on wheat yield: a simulation study

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Abstract
Soil organic carbon (SOC) is an important component of the natural capital of soil. Increased SOC can benefit crop growth by influencing soil processes and functions such as mineral nitrogen (N) supply to crops through its effect on N cycling, and water supply to crops through its effect on soil water characteristics. However, the relative contribution of these soil processes to grain yield is poorly understood. Crop models are increasingly used to investigate farming system productivity. Using the Agricultural Production Systems sIMulator (APSIM) model, we investigated the effect of particular soil processes, as affected by increased SOC in the top 0.1 m of the soil, on grain production for three Australian farming sites. At each site, we simulated wheat yield in scenarios where increased SOC was manipulated in the model to affect: (1) N cycling (i.e. N supply); (2) soil water characteristics (i.e. water supply); or (3) the combined effect of N cycling and soil water characteristics. Scenarios were simulated across five N fertiliser rates. We found that at low fertiliser rates, the effect of increased SOC on N cycling significantly increased simulated wheat yields. There was no similar effect at high fertiliser rates. The effect of increased SOC on soil water characteristics was much smaller than that on N cycling, but higher SOC increased crop yield at two of the three sites at high fertiliser rates. Quantitative estimates of the effect of increased SOC on crop yield are important in the context of managing SOC in Australian grains farms.

Key words
Modelling, wheat, productivity, soil organic carbon, nitrogen, APSIM

Introduction
Soil organic carbon (SOC) is an important component of the manageable natural capital of soils (Dominati et al. 2010) and can deliver a number of important ecosystem services, including contributing to crop productivity through its effect on physical, chemical, and biological soil properties and functions. For example, soil organic matter is a major store and source of nutrients, especially nitrogen (N). Furthermore, increased SOC can increase soil water supply through its effect on soil water characteristics. Given the decrease of SOC in some Australian agricultural soils due to past management practices, there is potential for agricultural management to increase SOC (Lou et al. 2014), particularly in the top 0.1 m of the soil where the majority of changes to SOC occur (Davy and Koen 2011). Higher levels of SOC have been linked to increased agricultural crop productivity in wheat farming systems (Lal 2004). Some studies have investigated the mechanism of this relationship in Australian cropping systems (e.g. Whitbread et al. 2000). A limitation of such studies is that they neither investigate which of the soil properties affected by SOC have the greatest effect on yield, nor how the effects vary across a range of soil types and climatic regimes.

Agricultural cropping models are increasingly being used to investigate soil, climate, and productivity dynamics of agricultural systems. These models provide a method to quantitatively assess the contribution of particular soil properties and functions, as affected by SOC, to crop yield across a range of soil, climate and management combinations. The Agricultural Production Systems sIMulator (APSIM) model has been developed in Australia and extensively validated for Australian wheat cropping systems, making it ideal for use in this study (Holzworth et al. 2014). APSIM has the inbuilt capacity to dynamically simulate changes in SOC and the resultant effect on N cycling which in turn influences N supply to crops. Carbon inputs to soils affect carbon flows between the carbon pools in APSIM which in turn affects the corresponding N flows which are calculated using the C:N ratio of the receiving N pool. This functionality is central to the SoilN module in APSIM (Holzworth et al. 2014). APSIM does not currently have the inbuilt capacity to dynamically simulate the effect of SOC on soil water characteristics which influence water supply to crops. However, the effects of SOC on soil water characteristics can be simulated by user-intervention (i.e. the user specifies parameter values that reflect changed SOC).

We report a simulation study on the effect of N cycling and soil water characteristics, as affected by changes in SOC, on grain yield in three Australian wheat farming systems using the APSIM model. We quantified the contribution of (1) N cycling (i.e. N supply), (2) soil water characteristics (i.e. water supply), and (3) the combined effect of N cycling and soil water characteristics to wheat yields.

Methods

The APSIM model (v7.5) was used to simulate soil, carbon, N, and water dynamics as well as grain production at three study sites. Study sites were chosen from within three different Australian wheat production agro-ecosystems; the Brigalow (26.88°S, 150.82°E) region in northeast Australia, the Mallee (35.80°S, 142.88°E) region in southeast Australia, and the Liebe region (30.27°S, 116.66°E) in Western Australia. Dryland cropping was practiced at all sites. Soil textures at the Brigalow, Mallee, and Liebe sites are clay, sandy clay loam, and sand, respectively. Soil parameter values used in APSIM were sourced from the APSoil database (www.apsim.info, accessed 5 May 2014), with the exception of more recently measured SOC content for the Mallee site (H van Rees 2014 pers. comm.). At each site, simulations were undertaken using the current SOC values in the soils (reflecting the past cropping system management) and with higher SOC values that reflect a theoretical SOC concentration that could be achieved under optimal management in the grain growing regions (Luo et al. 2014). To determine the relative effects of SOC on N and soil water supply to crops, four scenarios were simulated. In the first, termed the *Control* scenario, the soil with its 'original' SOC was simulated. In the second, the *Nitrogen Cycling* scenario, increased SOC affected only N cycling. In the third, the *Soil Water Characteristics* scenario, increased SOC affected only soil water characteristics. In the fourth, the *Combined Properties* scenario, SOC affected both N cycling and soil water characteristics. Pedo-transfer functions were used to relate the values of the main parameters affecting soil water in APSIM to SOC concentration (Palmer 2014).

Soil organic carbon in the top 0.1 m of the soil was increased from 1.19 to 2.19 % at the Brigalow site, from 1.20 to 2.20 % at the Mallee site and from 0.68 to 1.68 % at the Liebe site. This level of increase was based on estimated achievable increase under optimal management (Luo et al. 2014). Soil water parameters in APSIM include drained upper limit, lower limit, saturation water contents, and saturated hydraulic conductivity (specified for each soil layer). The water holding capacity of the soil, which is the total amount of water in the soil that a plant can access, is defined as the soil water held between the drained upper limit and the lower limit. These water parameters (drained upper limit, lower limit, saturation, saturated hydraulic conductivity) and bulk density were modified in the *Soil Water Characteristics* scenario. In this scenario, the plant available water in the top 0.1 m increased by between 1 and 3 mm with increased SOC, depending on the soil texture at the site. To avoid long-term changes of soil and water properties, which would confound the study, the SOC, mineral N, water, and surface residue values were 'reset' to initial values annually on the 1st January. Each scenario was simulated across five N fertiliser rates (0, 50, 100, 150, 200 kg N/ha). Management operations were specified to reflect common practice in each region with a continuous wheat cropping rotation and a summer fallow simulated at all sites. Daily climate data from 1963 to 2012 were obtained for each site from the meteorological stations nearest to the study sites. Using standard APSIM parameters the cultivars Hartog, Yitpi, and Mace were simulated at the Brigalow, Mallee, and Liebe sites respectively. Using the R statistical package (v3.1.2), the Wilcoxon signed-rank paired test was used to analyse the simulated yield for a significant difference between the *Control* scenario and the other scenarios.

Results and discussion

Nitrogen Cycling scenarios

Higher SOC significantly increased simulated wheat yields at low fertiliser rates at all three sites (Figure 1a, b, c). However, at higher fertiliser rates (between 100 and 200 kg N/ha depending on the site), high SOC had little or negligible effect on yields. In the Mallee site simulation with 0 kg N/ha, for example, the median yield in the *Nitrogen Cycling* scenario was 0.5 t/ha higher than the median yield in the *Control* scenario, whereas with 200 kg N/ha there was no difference (Figure 1b). The negligible effect of increased SOC on yields at higher fertiliser rates was expected, as N fertiliser dominated the N supply at high fertiliser rates. At low N fertiliser rates, the N supply to the crop was dominated by N derived from mineralisation of organic N. This result is consistent with field studies (e.g. Grace et al. 1995) that highlight N supply to crops from the 'consumption' of the SOC natural capital occurs as SOC stocks run down. In this study, simulated SOC content was annually reset. In a farming system, SOC would be depleted and the yield benefit would diminish unless inputs of organic material replaced the loss.

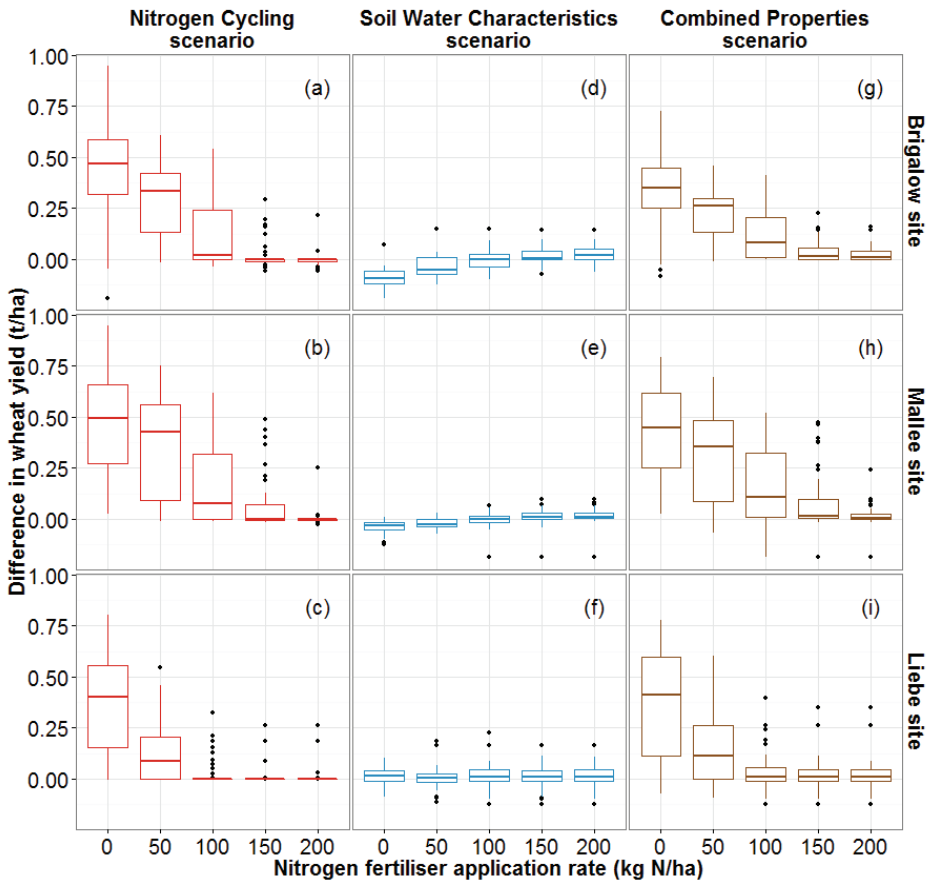

Figure 1: The difference in the simulated wheat yield between the *Control* scenario and the *Nitrogen Cycling, Soil Water Characteristics*, and *Combined Properties* scenarios, given increased soil organic carbon, for the Liebe, Brigalow, and Mallee simulations, under five nitrogen fertiliser rates. The data displayed represents simulated wheat yield from 1963 to 2012. Boxes show the 25th and 75th percentiles and the line shows the median value. Whiskers extend to the 10th and 90th percentiles and outliers are shown as points.

Soil Water Characteristics scenarios

The effect of changed soil water characteristics on simulated yields was much smaller than for the *Nitrogen Cycling* scenarios at all sites and there were interactions with fertiliser rate and site (Figure 1d, e, f). At low (i.e. 0 or 50 kg N/ha) fertiliser rates, the median yields in the *Soil Water Characteristics* scenarios were slightly lower than those in the *Control* scenarios at the Mallee (0.06 - 0.08 t/ha, Figure 1e) and Brigalow (0.03 - 0.04 t/ha, Figure 1d) sites. However, in a small number of individual years, yields were higher. At higher (i.e. 150 or 200 kg N/ha) fertiliser rates, median yields at these sites were slightly higher (up to 0.02 t/ha) with greater SOC. At the Liebe site (Figure 1f), increased SOC did not significantly affect yield at any fertiliser rate, with the exception of 0 kg N/ha where median yield was 0.02 t/ha higher than the *Control.*

Combined Properties scenarios

At fertiliser applications up to 100 kg N/ha, the simulated yields of the *Combined Properties* scenario (Figure 1g, h, i) were more like those of the *Nitrogen Cycling* scenario (Figure 1a, b, c) than those of the *Soil Water Characteristics* scenario (Figure 1d, e, f). At low (i.e. 0 or 50 kg N/ha) fertiliser rates, the *Combined Properties* scenario resulted in similar (Liebe, Figure 1i) or lower (Brigalow and Mallee, Figure 1g, h) simulated median yields compared with those for the *Nitrogen Cycling* scenario. At these low fertiliser rates at the Brigalow site, the range in predicted yields (i.e. the difference between the 25th and 75th percentiles) was less in the *Combined Properties* (Figure 1g) scenario than in the *Nitrogen Cycling* (Figure 1a) scenario. At all sites, when 100 kg N/ha was applied, median yield was higher in the *Combined Properties* scenario (Figure 1g, h, i) compared with the *Nitrogen Cycling* scenario (Figure 1a, b, c). The increase was highest (0.06 t/ha, Figure 1g) at the Brigalow site. At this fertiliser rate, the range in predicted yields (i.e. the difference between the 25th and 75th percentiles) for the *Combined Properties* scenario was smaller at the Brigalow site, similar at the Mallee site, and greater at the Liebe site, when compared to the *Nitrogen Cycling* scenario. At the highest fertiliser rates (i.e. 150 or 200 kg N/ha) the altered N cycling due to increased SOC had negligible effect on yield (Figure 1a, b, c). However, the combined effects of N cycling and water supply

due to increased SOC (i.e. the *Combined Properties* scenario) gave increased median yields at the Brigalow (Figure 1g) and Mallee (Figure 1h). The magnitude of the increases was similar to those in the *Soil Water Characteristics* scenario (Figure 1d, e).

Conclusion and future research

Soil organic carbon is an important component of the natural capital of the soil, delivering a number of important ecosystem services including crop productivity. This study found that the effect of increased SOC on N cycling provided a considerable yield increase at low fertiliser rates, but had very little effect at high fertiliser rates. Conversely, the effect of SOC on soil water supply had a much smaller effect on simulated yield than N cycling, but at high fertiliser rates, the increased water supply provided by higher SOC gave a small yield increase at two of the three sites. These findings are important in the context of managing SOC in Australian agricultural grains farms as they estimate the relative contribution of N supply and/or water supply, as affected by increased SOC, to wheat yield.

This study found relatively consistent effects of SOC across sites; however, considering a wider range of soil/climate/management combinations would provide a more comprehensive understanding of the magnitude of these effects. This study considered only the effect of SOC on grain yield. As SOC can influence many other ecosystem services, such as greenhouse mitigation (through SOC sequestration and nitrous oxide emissions) and off-site nitrate loss, further research could consider taking a more holistic view of the effects of SOC on ecosystem services and their benefits to grain farming systems.

Currently APSIM simulates only the effect of SOC on N cycling, and not on soil water characteristics (without user-intervention). The difference between the yield variation and yield response produced by the *Nitrogen Cycling* and by the *Combined Properties* scenarios (Figure 1) indicates that APSIM may currently be overestimating the effect of increased SOC on wheat yield at low fertiliser rates. Conversely, APSIM may be underestimating the effect at high fertiliser rates. APSIM is a widely used simulation tool. While there is inherent uncertainty associated with estimating the productivity of farming systems, further insights into crop management might arise from simulations where SOC also affects soil water characteristics, particularly in situations of high SOC change. Future development of APSIM could consider making soil water characteristics dynamically responsive to SOC. This could enhance the accuracy of APSIM when simulating agricultural systems.

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What carbon farming activities are West Australian farmers willing to adopt?

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Abstract
Transferring carbon from the atmosphere into terrestrial sinks through carbon farming has been proposed as an important component in Australia's efforts to mitigate greenhouse gas emissions. We use a Best-Worst Scaling survey to determine which carbon farming practices mixed crop-livestock and cropping-only farmers in the northern wheatbelt of Western Australia would be most and least likely to adopt. The survey was distributed via grower groups in Western Australia in August 2013. Farmers had strong preferences for stubble retention and no-till cropping. The practices that farmers were least willing to adopt were applying biochar and applying mulch. Farmers ranked improved soil quality and reduced soil erosion as the most important potential co-benefits of carbon farming. The research outcomes are discussed with respect to the implications for Australia's broadacre cropping industry and Australia's greenhouse gas abatement policies.

Key words
Carbon sequestration, farming systems, land use, policy, stated preferences, Best-Worst Ranking

Introduction

The Australian agricultural industry is responsible for 16 percent of national greenhouse gas emissions (DCCEE, 2010). One option for agriculture to contribute to national GHG emission reduction targets is through carbon farming. Carbon farming refers to a range of land use and land management practices designed to reduce emissions from farming activities, or sequester carbon in natural sinks such as soil and vegetation (Smith et al., 2008). The policy initiative at the forefront of efforts to reduce GHG emissions from agriculture in Australia is the Carbon Farming Initiative (CFI, Parliament of the Commonwealth of Australia, 2011).

An understanding of farmers' willingness to adopt carbon farming practices is needed to aid successful implementation of the CFI and similar policies. There exists a rich literature on farmers' adoption of environmental management and conservation farming practices (e.g. Knowler and Bradshaw, 2007; Pannell et al., 2006) Factors that have been found to be important in farmers' decisions to change agricultural management practices include: the (monetary and non-monetary) investment costs of the new practice; the impacts of the new practice on farm profitability; whether the practice 'fits' in the current farming system; farmer's financial situation and personal values; the social context in which the farmer operates; and the public (co-)benefits generated by adopting the practice.

Potential co-benefits of carbon sequestration in agricultural soils are: improved soil structure, reduced erosion, improved soil moisture retention, and increased plant available water and nutrient storing capacity (Lal, 2004). Returning land to native vegetation will promote carbon sequestration and can contribute to reduced salinity, improved water quality and improved ecosystem service provision (e.g. George *et al*. 2012). This study investigates whether farmers are willing to participate in carbon farming in light of the potential co-benefits that carbon farming practices can produce and which of these co-benefits are most important to farmers. We use a best-worst scaling survey to determine what carbon farming practices broadacre, dryland farmers in the northern wheatbelt of Western Australia are most and least likely to adopt.

Best Worst Scaling

Best Worst Scaling (BWS) is a survey method that requires respondents to select, from a set of objects, the object that they most prefer, and the object that they least prefer (Finn and Louviere 1992). In this study, the objects were carbon farming practices. Respondents were asked to choose the practice they would be most, and the practice they would be least likely to adopt, relative to the other carbon farming practices offered in the choice set (see Table 1). The choice task was repeated over 12 sets that contained different combinations

of the practices. This repetition of varied choice sets yields the information needed to calculate the preference scores of each respondent (Finn and Louviere 1992; Jones et al. 2013).

Table 1. An example of a Best Worst Scaling choice set from this study

MOST likely to adopt	Carbon farming practice	**LEAST** likely to adopt
◯	Retain crop stubble	◯
◯	Apply biochar	◯
◯	Plant tree belts	◯
◯	Plant perennial pastures	◯
◯	Apply mulch to bare soil	◯
◯	Adopt no-till cropping	◯

Analysis of Best Worst Scaling data

The best and worst selections in the BWS sets are used to rank the preferences for carbon farming practices for the aggregated survey sample. Using either a counting or regression approach we can generate the same preference ranking order (Finn and Louviere 1992). The counting technique involves summing, for each item, the number of times it was chosen as the 'most likely to adopt' minus the number of times it was chosen as 'least likely to adopt' (Finn and Louviere 1992). These scores can be rescaled by dividing the best minus worst score by the sample size (Marti 2012). In this survey design, each item appeared 8 times across the 12 choice sets. Therefore, the individual best minus worst scores range from –8 to +8. A score of +8 tells us that the carbon farming practice was chosen as 'most likely to adopt' by every farmer in every choice set that it appeared in. A score of -8 means that the practice was chosen as 'least likely to adopt' by every farmer in every choice set that the option appeared.

Survey design and distribution

Nine carbon farming practices were presented in the BWS choice sets. These nine practices were chosen based on a literature search and information gathered in a series of expert interviews. To understand the factors that could affect farmers' preferences or willingness to adopt certain activities, the BWS choice sets were accompanied by questions designed to elicit farmers' attitudes and opinions on climate change, climate change policies, and carbon farming. The link to the online survey was distributed to members of three grower groups: the Mingenew Irwin Group, the Liebe Group, and the North East Farming Futures Group. Responses were collected between 3 August and 2 September 2013.

Results

The following survey results are based on the responses of 43 mixed crop-livestock farmers and cropping only farmers from the northern wheatbelt of Western Australia. The median age of respondents was 40. Close to 80 percent of respondents stated that their farm was their only source of income. The average mixed crop-livestock farm was 7,120 ha with 65 percent dedicated to cropping, 20 percent to livestock and 15 percent left as remnant bush or land set aside for conservation. For cropping-only farmers the average land area was 6,900 ha with 85 percent dedicated to cropping and 15 percent has been left as remnant bush or set aside for conservation[1].

Factors affecting the decision to adopt carbon farming practices

Farmers were asked to rank six potential co-benefits of carbon farming practices in order of importance in their decision to adopt or not adopt carbon farming practices (Table 2). Improving soil quality was ranked as the most important benefit (relative to the other potential benefits presented) by 73 percent of mixed crop-livestock farmers and by 77 percent of cropping-only farmers. Selling carbon credits and carbon storage/reduced emissions did not appear to be important drivers of the decision to adopt carbon farming practices (Table 2).

Farmers' preferences for practice adoption

The preference order for adopting the nine carbon farming practices is presented in Table 3[2]. The two practices that were chosen most often as 'most likely to adopt' by both cropping only and mixed crop-

[1] Descriptive statistics of the sample are available from the authors upon request

[2] Results obtained from the regression method yielded the same preference order. Results are available from the authors upon request.

livestock farmers were retaining stubble and adopting no-till cropping practices. For mixed crop-livestock farmers, applying mulch was chosen most often as the practice that the farmers were least likely to adopt. For cropping only farmers the least preferred practice was applying biochar.

Table 2. Relative importance that mixed crop-livestock farmers (left) and cropping only farmers (right) placed on six potential benefits from carbon farming. The most important benefit is ranked as number 1.

Mixed crop-livestock farmers	Cropping only farmers
1. Improving soil quality	1. Improving soil quality
2. Reducing soil erosion	2. Reducing soil erosion
3. Enhancing biodiversity on farm	3. Landscape aesthetics/appearance
4. Carbon storage/reduced carbon emissions	4. Enhancing biodiversity on farm
5. Selling carbon credits	5. Selling carbon credits
6. Landscape aesthetics/appearance	6. Carbon storage/reduced carbon emissions

Table 3. Best Worst Scaling results for mixed crop-livestock farmers and cropping only farmers. These results are based on the number of times each practice was chosen as 'best' (Best Total) and the number of times the practice was chosen as 'worst' (Worst Total).

Carbon farming practice	Best Total	Worst Total	Best-Worst Total	Re-scaled Best-Worst Total
Mixed crop-livestock farmers (number of observations = 720)				
1. Retain stubble	168	0	168	5.6
2. Adopt no-till cropping practices	107	9	98	3.3
3. Plant perennial pastures	13	14	-1	-0.0
4. Implement rotational grazing	18	26	-8	-0.3
5. Increase pasture area (by decreasing crop area)	9	34	-25	-0.8
6. Inter-crop with perennial pastures	6	41	-35	-1.2
7. Plant tree belts	15	59	-44	-1.5
8. Apply biochar	12	85	-73	-2.4
9. Apply mulch to bare soil	12	92	-80	-2.7
Cropping only farmers (number of observations = 312)				
1. Retain stubble after crop harvest	69	0	69	5.3
2. Adopt no-till cropping practices	60	0	60	4.6
3. Establish areas of native vegetation	11	12	-1	-0.1
4. Plant tree belts	2	12	-10	-0.8
5. Plant perennial pastures	1	15	-14	-1.1
6. Inter-crop with perennial pastures	1	18	-17	-1.3
7. Apply mulch to bare soil	3	27	-24	-1.9
8. Plant trees for harvest e.g. oil mallees	7	38	-31	-2.4
9. Apply biochar	2	34	-32	-2.5

Discussion

The carbon farming practices that were preferred by both cropping and mixed crop-livestock farmers were 'retain stubble after crop harvest' and 'no-till cropping practices'. The high preference for retaining stubble and no-till cropping are likely to reflect farmers' perceptions of the production co-benefits associated with these two practices. Stubble retention and no-till cropping have been found to positively impact soil quality, which can subsequently have a positive impact on crop yield (Lal, 2004). The relationship between production benefits and likelihood of adoption is further confirmed by respondents ranking 'improved soil quality' and 'reduced soil erosion' as the most important co-benefits to be derived from carbon farming. The willingness to retain stubble and adopt no-till cropping practices could also be attributed to the relative ease with which these practices can be included in standard broadacre farming operations. In comparison, practices that do not readily fit within the existing farm enterprise mix received lower adoption preference scores in our study. For example, applying biochar, applying mulch and establishing areas of native vegetation or tree plantings, were often chosen as the practices farmers' were 'least likely to adopt'.

Of the six potential co-benefits of carbon farming presented to farmers in the survey, the least important co-benefits were those related to the opportunity to generate carbon credits and reduce the net greenhouse gas balance of the farm system. This finding strengthens our assumption that practices with benefits for farm producitivity are most likely to be adopted. Of course, farming systems vary between regions, as do the costs and benefits of changing agricultural practices. If we aim to achieve widespread adoption of carbon farming practices we will need two things: (1) a good understanding of the implications of carbon farming practices on agricultral production, and (2) flexible policies that allow farmers to select the carbon farming practices that are most appropriate for their farm system and their management strategy (Jones et al., 2013).

The challenge for farmers interested in carbon farming, is to know how much it will cost them to implement carbon farming activities. It is unlikely that farmers will participate in a carbon farming related policy such as the Carbon Farming Initiative or the newly introduced Emissions Reduction Fund if the costs are too high or benefits too low. The current study focussed on farmers' willingness to adopt carbon farming practices. The next step is to assess what carbon farming practices are able to deliver low-cost emissions reductions. Further research is ongoing to determine the whole-farm costs and benefits of different carbon farming practices.

Conclusions

In this study we collect information about the factors that affect farmers' decisions to adopt carbon farming practices. For a range of practices, we rank their preferences from 'most willing'' to 'least willing' to adopt. This study was done in light of increasing interest in agriculture as an industry that can reduce or offset greenhouse gas emissions. Our findings indicate that the motivating factors in the adoption of carbon farming practices are resource (soil) improvements and potential production benefits. As a result, it is not surprising that the practices farmers are most willing to adopt are retaining stubble and no-till cropping practices. It appears that and providing farmers with compensatory payments and additional information about the potential benefits of carbon farming activities is necessary to increase participation in policy schemes such as the Carbon Farming Initiative.

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Modeling the effects of mixed farming systems on soil carbon and crop-livestock productivity in central-west NSW

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Abstract
Simulation models are increasingly used for improvement of agricultural productivity through studying the interactions among biophysical processes in an agricultural farming system. In this study we used AusFarm (agricultural systems analysis model) to simulate crop and livestock performance including long-term soil organic carbon (SOC) dynamics under different management options such as conventional and reduced tillage, non-tillage with continuous cropping and perennial pasture in a grazing system. The AusFarm model was able to explain 70% of the observed variability in wheat grain yield with a RMSD of 554 kg/ha and showed good agreement between observed and simulated livestock performance. Simulated crop yield and gross margins were higher in conventional and reduced tillage with 2 -years annual pastures-cropping rotations than continuous cropping. In the long-term field experiment, the observed SOC increased initially, and were comparatively higher in reduced tillage than conventional practices. However, observed SOC decreased by 2012 in all other management options though SOC are higher in perennial pasture. The simulated trends of SOC under different farming system treatments were generally comparable with the observed field trial data. Although crops, pastures and livestock performance is related to timing of rainfall and amount of rainfall, equally, soil fertility decline can influence crop-livestock productivity. Long-term simulations suggest, cropping frequencies including crop-livestock rotation adjustments and soil-nutrient management are needed for productive mixed farming with environmental gains.

Key words
AusFarm, Crop rotation, Soil carbon, Simulation, Yield, Sheep weight

Introduction
With a focus on increasing productivity of mixed farms in the livestock dominate farming regions of NSW; practices involving reduced tillage, diverse crop rotations and altering the length of pasture phases may offer advantages. A key question is how modifications to this mixed farming system influence soil fertility through changes in SOC and the influence this has on crop and livestock productivity. In this study, long-term observations from the Central West Farming Systems trial at the Condobolin Research Station were used to validate AusFarm (Donnelly *et al*. 2002; Moore *et al*. 2007) with different management options for soil carbon and crop-livestock productivity. The other objective is to apply the validated AusFarm model to investigate SOC dynamics and crop-livestock performance as influenced by different mixed farming practices.

Methods
Site and treatment: This study involves a long-term field experiment conducted by Central West Farming Systems (CWFS) that commenced in 1998 and is continuing at Condobolin Research Station (33.07°S, 147.23°E). The site is characterised by a hot semi-arid climate with an average annual precipitation of 442 mm and a mean annual temperature of 17.4°C. The soil is a Red kandosol soil (Isbell 1996) with SOC content of about 1.30% in 0-10 cm soil depth. This is a representative of a rainfed crop-livestock growing location in the central-west NSW. The CWFS site covers 160 ha area. This area is divided into 40 ha blocks. 10 ha areas within each block are randomly assigned to 1 of 4 farming system: a traditional farming system with conventional tillage (CT), reduced tillage with livestock (RT), zero-tillage with no livestock(ZT) and perennial pastures (PP). The CT represents a mixed farming system that uses conventional tillage with a pasture phase, wheat phase of long fallow wheat (LFW) and short fallow wheat (SFW) under-sown with pasture combinations. The RT represents reduced tillage with rotations of LFW, SFW, grazed pasture and a period of rest and naturalised pasture between wheat crops. The ZT represents continuous a cropping rotation with wheat, barley and field pea.

Simulation

The AusFarm model (http://www.grazplan.csiro.au) was used to link the APSIM crop and soil models (Keating *et al*. 2003) and the GRAZPLAN pasture and animal management models (Freer *et al*. 1997; Donnelly *et al*. 2002; Moore *et al*. 2007) are used to represent CT, RT and ZT mixed crop-livestock farming practices. Briefly, AusFarm simulates biological and physical processes in a mixed-farming system in response to climate (daily maximum and minimum temperature, rainfall and solar radiation), in-crop management, livestock enterprises and animal husbandry practices. Crop yield and animal performance (Medium Merino) data from 1998 to 2012 comprising CT, RT and ZT farming systems were used to validate the AusFarm model. Performance was evaluated against the observed measurement by comparing the coefficient of determination and root mean square deviation (RMSD). The effects of tillage and frequencies of cropping with annual pasture phase on SOC and in turn to crop-livestock productivity were examined by long-term simulations (1 January 1889–31 December 2014) using historical climate (daily solar radiation, maximum temperature, minimum temperature and rainfall) data obtained from SILO patched point datasets (http://www.longpaddock.qld.gov.au/silo/ppd/index). A mixed crop-livestock farming scenario representative of central-west NSW was developed in the AusFarm platform. Parameters information available in Primefacts (http://www.dpi.nsw.gov.au/aboutus/resources/factsheets/agriculture) pertaining to crop management, sheep enterprises and animal husbandry practices were used in the simulations setup which is similar to existing mixed-farming system in central-west NSW region. The farm area assigned in the simulation is 1000 hectare, where 30% constitutes permanent pastures (phalaris) to represent naturalised grazing pasture for use sheep grazing (Medium Merino of 5.25 Ewes/farm ha) and reminder 70% as arable land divided into seven paddocks to facilitate crop sequences and annual pastures (sub-clover and annual Ryegrass). We considered four simulation treatments: (1) CT_APCW represents conventional tillage (CT) with a rotation of 2 -years annual pasture (AP)/wheat/canola/wheat/canola; (2) CT_CW represents CT with continuous canola and wheat; (3) RT_APCW represents reduced tillage (RT) with a rotation of 2 -years annual pasture/wheat/canola/wheat/canola and (4) RT_CW represents RT with continuous canola and wheat. Gross margins ($/ha) were estimated using the variable costs based on 2012 farm budget and costs data (http://www.dpi.nsw.gov.au/agriculture/farm-business/budgets).

Results and Discussion

The AusFarm model was able to explain 70% of the observed variability in wheat grain yield with a RMSD of 554 kg/ha (Fig. 1A). In 2002 (the only year with records), comparison of simulated and observed lamb sale weight and fleece weight showed adequate level of prediction (Fig. 1B and C).

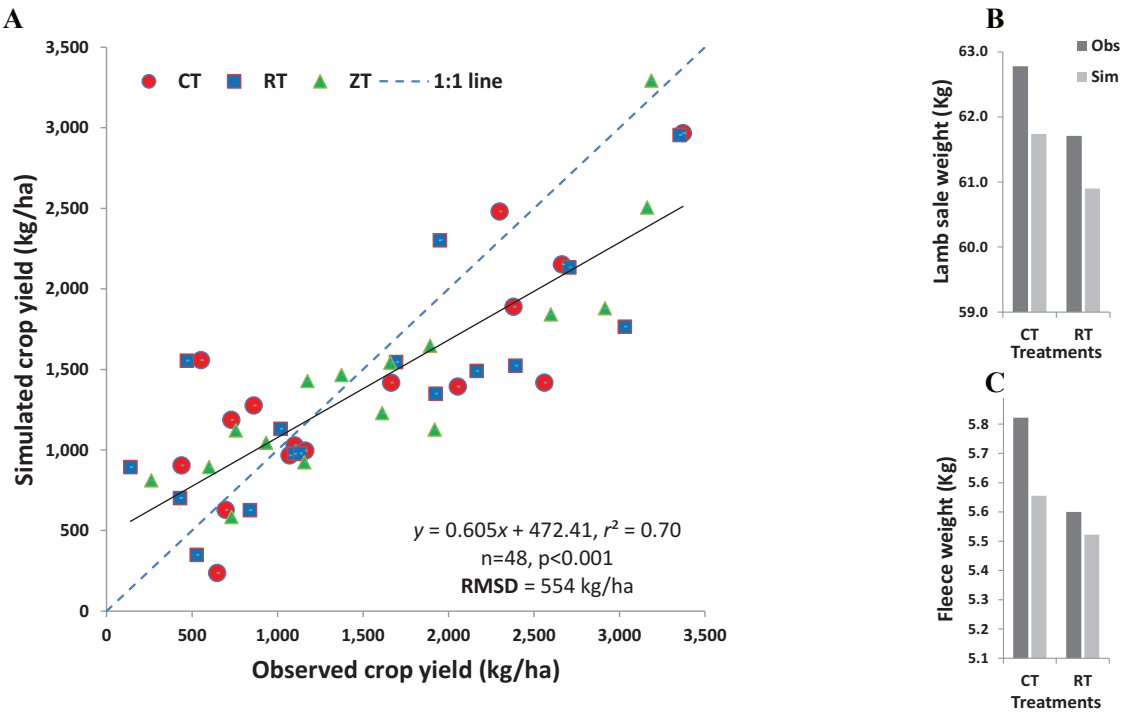

Figure 1. Comparison of simulated and observed wheat yields (A), animal weight (B) and fleece weight (C) for experimental data comprising traditional farming system (CT), reduced tillage with livestock (RT) and zero-tillage with no-livestock (ZT). Animal weight and fleece weight were only for year 2002.

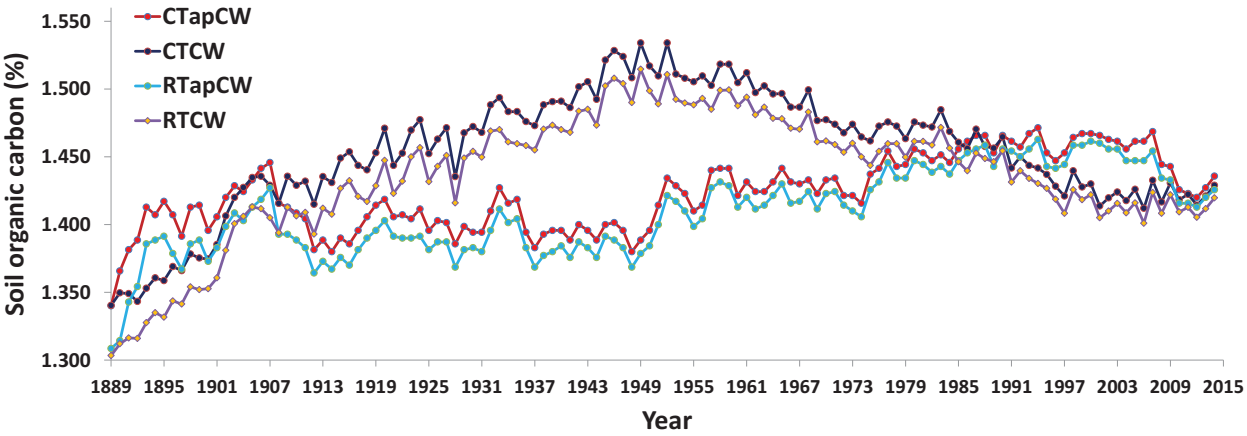

Figure 2. Simulated soil organic carbon (%) in the 0 – 10 cm soil profile across conventional tillage (CT) with pasture-cropping rotation (CT_APCW), CT with continuous cropping (CT_CW), reduced tillage (RT) with pasture-cropping rotation (RT_APCW) and RT with continuous cropping (RT_CW).

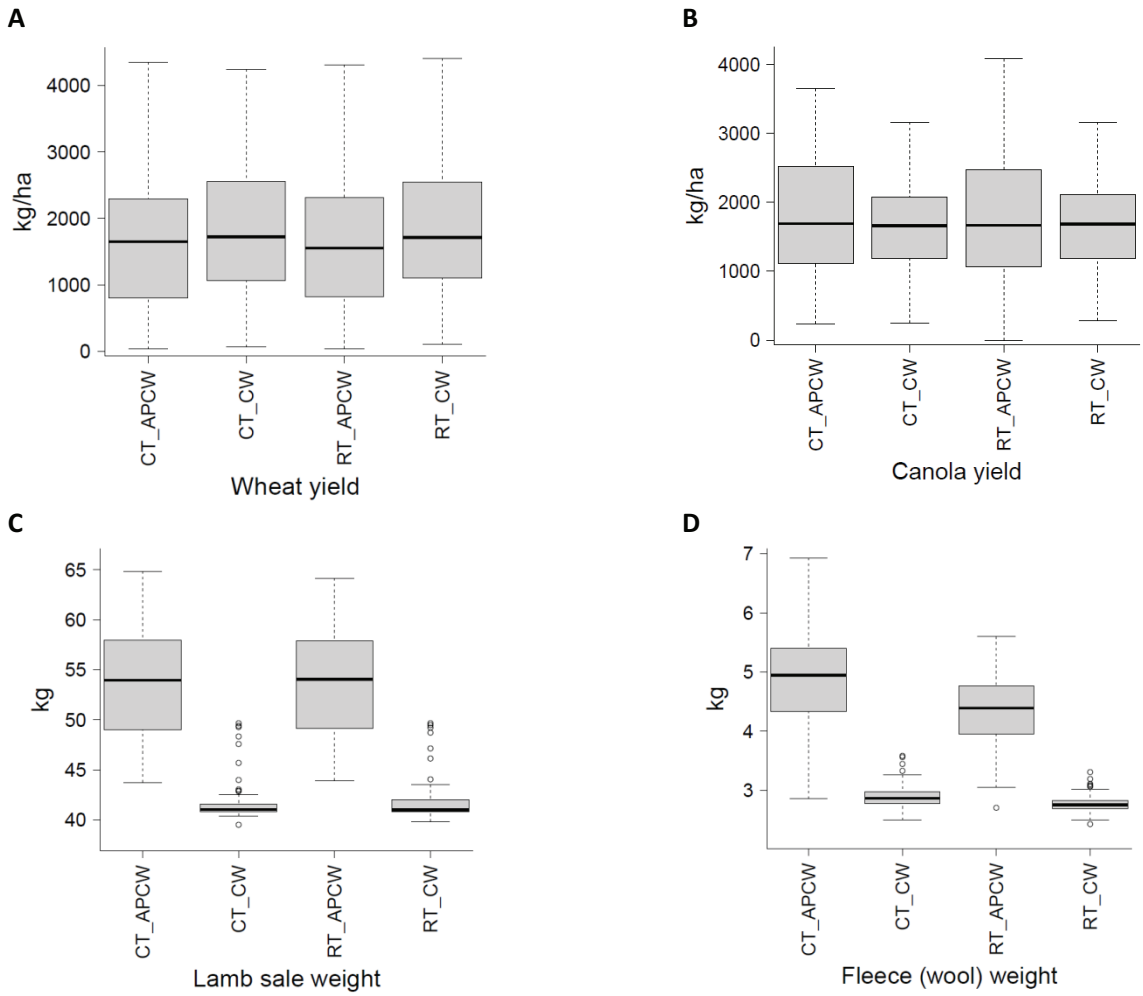

Figure 3. Box-plot of simulated crop yields (A and B), animal and fleece weight (C and D) across conventional tillage (CT) with pasture-cropping rotation (CT_APCW), CT with continuous cropping (CT_CW), reduced tillage (RT) with pasture-cropping rotation (RT_APCW) and RT with continuous cropping (RT_CW) treatments. Livestock in all systems have access to permanent phalaris pasture.

In the long-term field experiment observed SOC increased initially, and were comparatively higher in reduced tillage than conventional practices (data not shown). However, in the long-term field experiment, the observed SOC decreased by 2012 in all other management options though SOC are higher in perennial pasture. Likewise, simulated SOC increased continuously during the long-term (Fig. 2) across all farming

practices. However, after an initial increase, modelled SOC under CT_CW and RT_CW declines rapidly after 1950, implying more organic inputs due to higher frequencies of cropping, and later decline could be attributed to reduced microbial substrate for biochemical activity. In contrast, increasing SOC under CT_APCW and RT_APCW is fairly stable (Chan *et al*. 2010).

The simulated median crop (wheat and canola) were not different between the four mixed farming systems (Fig. 3). However, dispersion of the distribution of long-term canola yield reduced (Fig. 3B) in CT_CW and RT_CW farming systems. Performance of sheep in terms of lamb sale weight and fleece weight was highest (Fig. 3C and D) with the introduction of 2-years annual pastures in the cropping rotation (CT_APCW and RT_APCW). With the introduction of annual pasture component in the farming system, gross margins were higher in CT_APCW and RT_APCW compared to CT_CW and RT_CW (Fig. 4). In a mixed crop-livestock systems including pasture can reduce supplementary feeding costs, complementing better farm profitability.

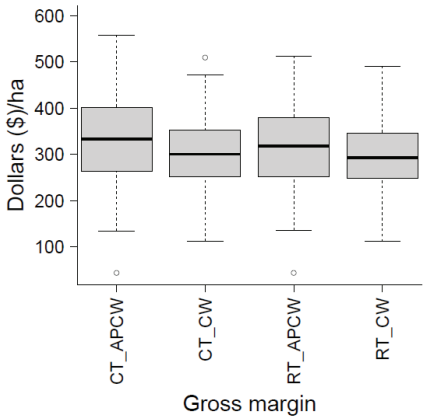

Figure 4. Relative frequency (%) distribution (125 years) of Gross Margins ($/ha) calculated from simulated crop-livestock productivity across conventional tillage (CT) with pasture-cropping rotation (CT_APCW), CT with continuous cropping (CT_CW), reduced tillage (RT) with pasture-cropping rotation (RT_APCW) and RT with continuous cropping (RT_CW) treatments.

Conclusion

Simulations indicate that Ausfarm captured the physiological processes satisfactorily for different tillage managements, and the model was able to explain 70% of the observed variability in crop yield with a RMSD of 554 kg/ha. The simulated trends of SOC under different farming system treatments were generally comparable with the observed field trial trends. There were stable trends of increasing of SOC in both conventional and reduced tillage with 2 -years annual pasture-cropping rotations than continuous cropping.

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Developing conservation agricultural innovations and practice change: a model for future research, development, extension and training in a brave new world

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Abstract
Incorporating crop residues (stubble) after harvest and adding soil nutrients (fertiliser) is thought to increase soil carbon. However, this has not been quantified over a range of soil types, climates and farming systems. The impact of this practice on grain yield and soil carbon in broad acre cropping was tested in a large collaborative project undertaken by a consortium of farming systems and grower groups, extension personnel and researchers. The project: 1. gauged growers' attitudes to the benefits of stubble management and carbon farming; 2. determined the need for, and provided training in soil carbon and biology; and 3. conducted a field experiment to measure the impact of stubble incorporation and nutrient addition on soil carbon and grain yield at 14 sites from the eastern wheat-belt central NSW to south-west Victoria. Most growers were sceptical of stubble incorporation as a technique for sequestering carbon but recognised the need to quantify benefits and costs. Integration of stubble incorporation must provide financial returns and flexibility in farming systems. Growers were keen to undertake broad training in soil biology rather than focusing on soil carbon alone. The field experiment had variable success and identified the needs of such an ambitious approach to research. These are: clear experimental protocols, careful site selection, excellent communication, sufficient resources, and the clear definition of the roles and responsibilities of partners. We identify both the benefits and problems of a collaborative consortium. The engaged partners are keen to further develop this model for future collaboration.

Keywords
On-farm research, herbicide resistance, low-input systems, socio-economic drivers, adaptation, participatory research

Introduction
Conservation agriculture (CA) with stubble (crop residue) retention and reduced or no-till has clear benefits and costs for the dryland and irrigated mixed farming systems of south-eastern Australia (Scott *et al*. 2010; Kirkegaard *et al*. 2014). CA increases ground cover and soil conservation, reduces energy and labour costs, increases water use efficiency, improves timeliness of sowing, and reduces environmental and human health risks from smoke pollution. In addition, evidence suggests that stubble incorporation after harvest with added nutrients (nitrogen, phosphorus and sulphur) can significantly increase soil carbon sequestration in the top layers of soil (Kirkby *et al.* 2011). However, tillage and stubble burning are replaced by herbicides for weed control in CA, leading to increased selection pressure and widespread herbicide resistance worldwide, especially to glyphosate in crops and fallows (Heap 2014). Crop competition through plant breeding and agronomy (Lemerle *et al*. 2001) has gained renewed interest recently for weed management. Other constraints to CA include difficulties in sowing into high stubble loads, increased machinery costs, and more complex management decisions. As a result, rates of adoption have been relatively slow in this zone (e.g. Llewellyn *et al*. 2012). Many growers now are utilising 'strategic' tillage and burning of stubble for weed, disease and pest control (Kirkegaard *et al*. 2014; Higgins *et al*. 2015). Recently, political pressures for

environmental protection and adaption to climate change have increased government incentives for farmers to adopt conservation agriculture. Clearly, both complex biophysical and socio-economic factors influence adoption of new farming systems and adoption is more likely if systems are more flexible, profitable and resilient to the challenges of climate change, rising costs and herbicide resistance.

This paper describes an Australian Commonwealth Government-funded project (*Action on the Ground Program* 2012/3 -2014/5) that examined the relationships between stubble/nutrient practices (from 'burnt' to 'fully incorporated with nutrients') on soil carbon and grain productivity from a regional perspective. The aim was to develop a multi-disciplinary consortium of dryland and irrigated systems groups, advisers and researchers for collaboration and integrated research, development, extension and training (RDE&T). The project combined on-farm experimentation with training of farmers and advisers, and also included social science studies of farmers' knowledge, attitudes and practices. Communication and extension activities were an important component of the project.

RDE&T Consortium

The consortium was formed in 2012 between farming systems groups (Central West Farming Systems, FarmLink and Southern Farming Systems), a consultancy (Rural Management Strategies, Wagga Wagga), the research subsidiary of the rice growers cooperative company (Rice Research Australia Proprietary Limited), Holbrook Landcare Network and researchers at the Graham Centre for Agricultural Innovation, an alliance between Charles Sturt University (CSU) and the New South Wales Department of Primary Industries (NSW DPI). The partners covered a wide range of growing conditions and soil types from the eastern wheat-belt of central NSW to south-west Victoria. The annual average rainfall was between 408 and 624 mm, growing season (April-November) rainfall between 247 and 351 mm, with expected average wheat yields of between 1 and 4 t/ha, and up to 8t/ha for irrigated systems. The scale and nature of farming operations varied between partners and thus the techniques were tested under a wide range of stubble load and breakdown conditions. The aim was to provide information and experience in stubble techniques and examine the benefits/costs of stubble for carbon farming to over 1500 farmers across the broad range of environments. Information and innovation was shared between growers, advisors and researchers across the region. Demonstrations of the latest research locally aimed to provide knowledge confidence and capacity for practice change and for landholders to understand impacts on soil carbon.

Field experiment conducted at 14 sites

Three core treatments were tested at all locations: current local practice (usually standing stubble), stubble incorporated with a disced implement, stubble incorporated with extra nutrients applied according to the stubble load at the time of application. Some groups tested other treatments, for example nutrients applied to standing stubble. The variability of each site was assessed by electromagnetic surveys. Two zones were identified within each field which were used as 'blocks' in a replicated block statistical design. All trials were undertaken by farmers using their own equipment with the width of each plot being dictated by the width of the machinery. Protocols to sample stubble and soil were devised in conjunction with the farming systems groups. Soil sampling was carried out to determine the initial, pre-treatment, values of soil carbon. Grain yield was measured using a variety of methods.

Detailed plans were drawn up for twelve field trials and communicated to the project partners. Ten of those experiments were established in 2013 as planned and grain yields were harvested in 2013 and 2014. The partners where this was achieved were close to Wagga Wagga or had a history of collaboration with NSW DPI and CSU. Soil carbon values were low at all sites and generally 50% of soil carbon was in the humic fraction. The initial, pre-treatment, soil carbon content in the top 10 cm of soil increased with increasing annual rainfall. A number of important issues were identified while establishing the sites, including that it was a complex process that took much longer than anticipated. Advisers felt that the experiment focussed too much on the science and was insufficiently resourced to achieve the objectives. Communication could have been much better; however, competing demands on people's time was an on-going problem. Of critical importance was having the right farmers and sites who are happy to be involved and willing to participate. Also, uniformity of equipment across all sites was important to reduce variation in grain yield results, and so the success of measuring yield by on-header harvest yield monitors was variable. Again, those partners who were local and had a history of collaboration delivered the best results. Some yield monitors failed, one was set to record at thresholds above that which would identify variation in the paddock, and some monitors

suffered data loss. Those yield data recorded showed no clear effect of the treatments. It seems likely that variation in yield was dominated by weather events like frost or drought. Short-term yield benefits were of more interest to the farmers than longer-term changes in soil carbon.

Soil biology and carbon training

Training workshops were delivered to 221 landholders in Soil Biology (153 participants) and Soil Carbon (68 participants) from June 2012 to April 2014, by NSW DPI staff with some workshops co-delivered by Riverina Local Land Services staff as a 'train the trainer' program. Face-to-face training was delivered, and in addition, participants were shown how to access the *Evertrain* online courses (www.futurefarmonline.com.au/agribusiness...evertrain.htm.) at the training days. Evaluation surveys indicate some participant interest in the online courses. The more popular Soil Biology course was designed to provide participants with knowledge about the functions of soil organisms, and highlighted the importance of soil organisms for soil health. The course presented techniques to identify and monitor soil biological health and manage soil organisms for sustainable land management. The Soil Carbon course enabled farmers to develop an understanding of the carbon cycle, by examining different types of soil carbon, location, measurement and benefits to the soil, and for mitigation of climate change under different soil types and climatic zones. There was an overall positive response from participants to the workshops due to the: practical component of the courses; opportunity for participants' to examine their own soils; use of local advisory staff where possible to tailor content to regions; and group discussions that enabled land managers to share experiences and ask questions.

Social research

The broad aim of the social research component of the project was to assess growers' knowledge, understanding and practices of stubble management at the beginning of the project, and following the field trials. To achieve this aim the social research was divided into two phases. The first phase involved group interviews in June, July and September 2013 with a sample of landholders from each of the six grower groups involved in the project, as well as individual semi-structured interviews with two growers from each group. The group interviews provided valuable baseline data on landholders' knowledge, understanding and practices of stubble management. Individual in-depth interviews enabled more detailed exploration of, as well as insights into, stubble management practices. It was found that partial adoption of stubble retention is normal, with many using it as a tool in their stubble management kit (Higgins *et al.* 2015). Growers showed little interest in carbon sequestration, and they were sceptical about measuring soil carbon, maybe due to cost, accuracy and need. Growers partially adopt stubble retention and combine this with selective burning under a 'flexible combined system' of stubble management. The second phase of the social research commenced in late March 2015. This phase involves semi-structured interviews with the grower group leaders/coordinators as well as two growers involved in the field trials from each group (total of 18 interviews). Changes in attitudes and knowledge will be benchmarked, as well as future RDE&T needs.

Communication and extension activities

An annual forum aimed to provide a platform for the growers, researchers and industry experts to engage and network, building knowledge and understanding about the use of stubble for carbon sequestration and sustainable cropping. However, this was poorly attended by farmers and advisers. Field days were generally well attended especially those involving machinery and demonstrations, which really engaged the farmers and resulted in good and robust discussion between the farmers and researchers. It was obvious that growers require information that relates to practical application on-farm. It was also noted that for engagement of growers at the field sites it is important to have consistent messages about carbon farming, realising that systems are very complicated, i.e. regional and farmer specific. Field events which targeted farmers and industry aimed at increasing knowledge and understanding about the role of stubble for carbon sequestration, soil microbiology, soil acidity, and other management decisions experienced with stubble retention. Internal communications amongst project partners occurred regularly with email updates and a webpage of project activities being circulated, however, feedback suggested there was room for improvement.

Conclusions and future directions

In early 2015, two and a half years after the project commenced, a number of conclusions could be drawn about the successes and problems of forming such a consortium for collaboration. It was generally agreed that the project has created an important framework to look at systems and integration, and that linking researchers and growers is important for generating and testing 'science-based' innovations and providing

reliable advice for farmers. The integration of training was a very important component of the project. The benefits of a multi-disciplinary team were clear and essential to address the complex biophysical and socio-economic drivers in CA systems. However, the integration of 'business management' into the project was required to examine risk management and quantifying the costs and benefits of innovations. The project was over ambitious given the limited budget, and it would have benefited from a longer planning phase. In future, such projects should have simple objectives with obvious benefits to farmers and last long enough to measure changes in soil properties, as well as short-term yields. The number of partners and the area covered was probably too large for a preliminary study. In future, effective collaboration and the building of trust between partners require more time, resources and better communication. It was suggested that a half-day training and team-building meeting of the farming systems group leaders and the researchers is required at the beginning of such a project, to agree on objectives, go through the protocols, and establish an understanding of the roles and responsibilities of partners. This is critical to ensure clear and consistent communication to the farmers. Considerable opportunities exist to improve communication of 'reliable' advice, especially through the use of social media and for new models for field days, including careful choice of demo sites with the right farmer champions. The engaged partners identified a will to continue such an RDE&T collaboration to address future priorities, including herbicide-resistant weeds, rising input costs, and the potential of precision agriculture, and the integration of livestock enterprises into mixed farming CA systems. Engagement using soil carbon, which farmers have little interest in, is unlikely to succeed.

In summary, the participatory research model works but lessons learnt are: effective communication is critical; distance covered must be manageable; on-farm experimentation is important but there can be problems with different equipment used at different sites and conflicting priorities; the need for achievable research questions about potential new techniques; long-term funding is required; established trusting relationships are most effective when roles and responsibilities are well defined and resourcing adequate; integration of social and economic sciences are important for understanding the knowledge and motivation of farmers for change; and benefit cost analyses. Long-term experiments combined with reliable advice underpin the adoption of new innovations.

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Modelling soil organic carbon 1. The value of long term agronomic experimental data

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Abstract
The performance of the APSIM agricultural systems model was compared with measured soil organic carbon (SOC) from three long term experiments over a period of 24-44 years. The experiments involved continuous grazing of improved pasture (Hamilton, Victoria), continuous legume-wheat cropping (Wagga Wagga, New South Wales) and continuous wheat/barley cropping (Warwick, Queensland). The model was initialized for the soil type of the experimental sites using default parameters that define the soil C fractions but rate constants were identical for the three locations. The biophysical simulation model in the APSIM framework explained well the observed changes in SOC at the various locations without specifically fitting the model to the observed data, despite large variation in the measured data. This indicates that the SOC model was robust over the moderate to long term period. As such the model is suitable to extrapolate a simulated response beyond these locations under various treatment combinations that should predict realistic SOC stocks within the expected mean error of less than 10% (3 to 6 t C/ha 0-30 cm). New long term experiments should be developed in Australia that specifically aim to increase SOC.

Key words
Modelling, validation, carbon accounting

Introduction
Simulation models of crops that involve SOC dynamics can provide robust and objective methods to extrapolate likely changes in SOC in response to management and climate change over different landscapes and time periods (Grace et al. 2006; Liu et al. 2009; 2014). We examine the performance of the APSIM cropping systems model (McGowan et al 1996) with respect to its ability to simulate soil C in pasture and cropping rotations in three long term agricultural experiments (LTAE) over 24-44 years in eastern Australia. This study (Part 1) was intended to enhance the model capacity for filling research gaps for the management of SOC in cropping and pasture systems (Part 2).

Methods
Soil organic carbon data that had been collected from three long term agricultural crop and pasture experiments were selected from eastern Australia to test the performance of the APSIM cropping systems models with respect to SOC. These long term experiments have been managed for over 22 to 44 years and represent a valuable resource to study SOC – dynamics that are difficult to measure in short term experiments because of the slow changes that occur in nature. The sites – Hamilton, Victoria (Cayley et al. 1998 Cayley et al. 1999; Clark et al. 2003), Wagga Wagga, New South Wales (Chan et al., 1992; 2002; 2011; Heenan et al., 2004) and Warwick, Queensland, Australia (Loch and Coughlan 1984; Marley and Littler 1989) were selected to represent a climatic gradient from Victoria to Queensland.

Various modules of the APSIM farming systems modelling package were selected for this study. The APSIM system is useful in analyses of crop and pasture systems because of the wide range of crops and pasture available (Keating et al. 2003) and the interconnected soil environment that enables at least some focus on SOC. Each crop and pasture inputs biomass into the soil in an automatic way.

The crop modules selected were wheat and barley and the pasture module was the AGPASTURE module (Li et al. 2011). We selected various pasture/stocking rate treatments and cropping treatments that would be typical of such systems at the three locations. The model was initialised using soil characteristics defined at the experimental sites.

Results and Discussion

Comparison of observed and simulated SOC shows good agreement at the three locations. At Hamilton measured SOC did not change significantly over 32 years and the model represented this well (overall RMSE = 5.0 t C/ha, Figure 1). The present levels of SOC appear to be at equilibrium at the same level for a range of pasture productivity levels and stocking rate (data not shown).

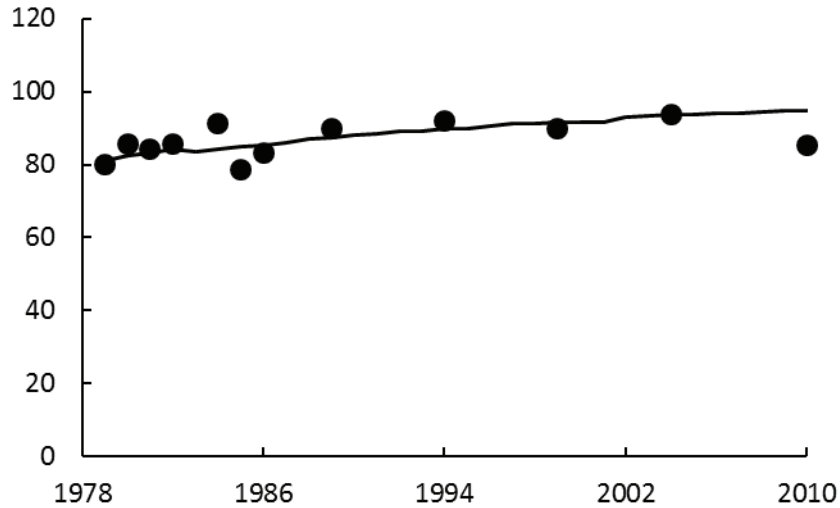

Figure 1. Comparison of observed (●) and simulated (—) soil organic carbon (0-30 cm) changes over 32 years at Hamilton VIC, under a moderate pasture productivity level (4 kg P/ha) and continuously grazed stocking rate (6 ewes/ha).

In contrast, over twenty-four years of continuous cropping at Wagga Wagga under a Wheat-Lupin crop rotation under stubble retention and zero tillage a neutral trend over time was seen (overall RMSE = 3.3 t C/ha, Figure 2.) There were no significant differences between phases of the same rotation in the simulated data. This rotation also appears at equilibrium despite the much lower total SOC compared to that at Hamilton.

Thirty years of continuous cropping at the Queensland site resulted is significant declines in soil C irrespective of the farming practices applied. Figure 3 shows this decline in a conventionally tilled system with stubble burning and a moderate rate of N fertiliser. Higher amounts of N reduced the rate of decline in the presence of stubble (data not shown). Overall, the modelled changes in soil C matched reasonably well the observed behaviour with the greatest decline under zero N application (overall RMSE = 3.7 t C/ha).

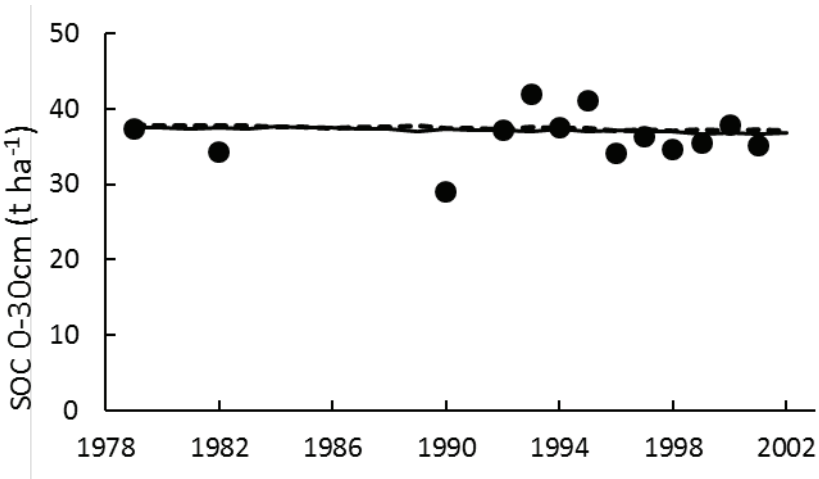

Figure 2. Comparison of observed (●) and simulated (solid line: wheat-lupin; broken line lupin-wheat rotation) soil organic carbon (0-30 cm) changes over 24 years at Wagga Wagga NSW.

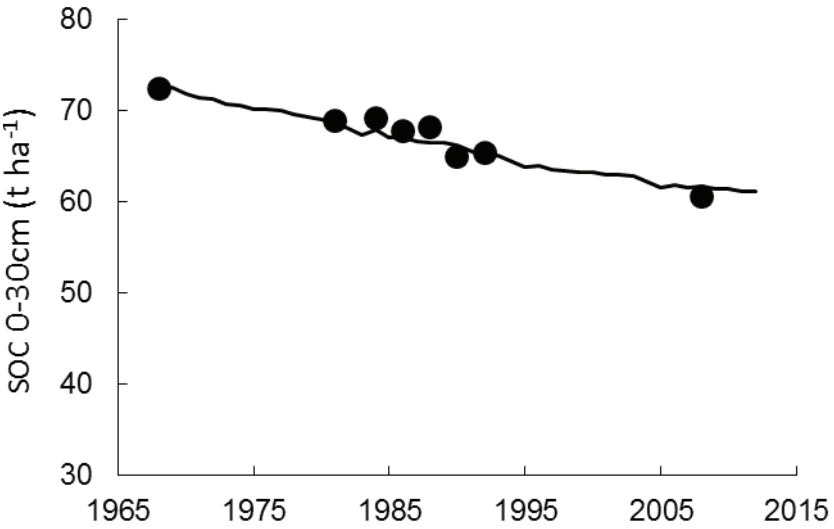

Figure 3. Comparison of observed (●) and simulated (—) soil organic carbon (0-30 cm) changes over 44 years at the Warwick QLD, site under a continuous crop rotation of wheat and barley with stubble burning (SB), conventional tillage (CT) and a moderate application rate of nitrogen (2N).

The effect of various management practices on SOC appears to also be well captured by the model. An important question is what management options are realistically available to farmers to increase or maintain the highest practical SOC level. The challenge is to achieve sufficient productivity benefit with minimal negative effect on SOC. One of the obvious limitations of long term agronomic data for studying changes in SOC is that the original treatments were not specifically designed to increase SOC. What we see is the resultant changes from an agronomically-focused experiment. New long term experiments should be developed in Australia that specifically aims to increase SOC. Using modelling we explore in Part 2 options involving pasture and cropping rotations that offer more potential than the options tested in these long term agronomic experiments to increase SOC storage across eastern Australia.

Conclusion

The long term agronomic experiments used in this study were considered important locally to examine long term sustainability issues at each site. However, their value when considered together, through simulation modelling, probably exceeds the original expectations of their designers. The biophysical simulation model exemplified by the APSIM model explained well the observed changes in SOC at the various locations without specifically fitting the model to the observed data. As such the model is considered robust and suitable to extrapolate a simulated response beyond these locations under various treatment combinations that should predict realistic SOC stocks within the expected mean error of less than 10% (3 to 6 t C/ha 0-30 cm).

Acknowledgements

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Effects of future atmospheric CO_2 concentration on the productivity and nitrogen fixation of pulses under Free Air CO_2 Enrichment

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Abstract
Future atmospheric CO_2 levels are expected to increase from current levels of approximately 400 µmol mol^{-1} to 550 µmol mol^{-1} by 2050. This is a very rapid increase in one of the fundamental resources for plant growth. To determine the effects that this will have on dryland agricultural systems, the Australian Grains Free Air CO_2 Enrichment (AGFACE) facility was established in 2007 in Horsham, Victoria. AGFACE comprises 8 rings in a complete randomised block design treated with either ambient (a[CO_2] ~ 400 ppm) or elevated (e[CO_2] ~ 550 ppm) CO_2. From 2010 to 2012, five cultivars of field peas (Pisum sativum) were grown in AGFACE; in 2013 and 2014 lentils (Lens culinaris) were grown (6 cultivars). The research questions have moved from effect-type questions (does growth and yield increase under e[CO_2]?) to physiological questions trying to resolve whether genotypic differences exist in response to e[CO_2] with a particular emphasis on water and nitrogen (N) use efficiency related traits. Yields were increased by e[CO_2], from 16% to 39% for field peas, and from 34% to 147% in lentils. Small but significant reductions in leaf and grain N were found, contrary to expectations. In addition, N contribution from pulses appear to be increased by the higher biomass under e[CO_2], but not by a greater proportion of N derived from fixation.

Key words
Climate change adaptation, genotypic variability, pulse pre-breeding

Introduction
Atmospheric CO_2 concentrations ([CO_2]) have been increasing from about 280 ppm to 400 ppm from the pre-industrial era until now (March 2015; www.co2now.org). This increase in one of the fundamental resources of plant life, the substrate of photosynthesis, has direct implications for plant metabolism.

While it is well established that elevated [CO_2] (e[CO_2]) increases plant growth and yield, it is also thought to increase water use efficiency and nutrient use efficiency (Leakey et al 2009). However, these results have been observed in Free Air CO_2 enrichment (FACE) facilities in environments with higher natural rainfall and/or irrigated agricultural systems and there were concerns that they might not apply to relative low rainfall Australian dryland agriculture. The Australian Grains Free Air CO_2 Enrichment (AGFACE) facility was established in 2007. Over the last eight years, the research questions have evolved from effect-type questions (does growth and yield increase under e[CO_2]?) to physiological questions trying to resolve whether genotypic differences exist in response to e[CO_2] with a particular emphasis on water and nitrogen (N) use efficiency related traits.

Pulses are increasingly seen as an essential component of sustainable agricultural systems as a high value commodity in themselves as well as due to their ability to contribute N to the cropping system via symbiotic fixation. Elevated [CO_2] could help this symbiosis by providing extra assimilates to bacteria, and increase the N contribution of legumes to the subsequent crop. Under e[CO_2], cereals also tend to show decreased grain protein and nutrient concentrations (Högy and Fangmeier 2008), but legumes should not be susceptible to this dilution (Jablonski et al 2002).

Materials and Methods
The AGFACE facility is located near Horsham, Victoria on a cracking clay (Vertosol) soil. A detailed description of the site and the CO_2 exposure equipment is given in Mollah et al (2009). Briefly, the study site has approximately 35% clay content at the surface increasing to 60% at 1.4 m depth. Elevated CO_2 levels

(target 550 µmol mol^{-1} air) were maintained during daylight hours by injecting pure CO_2 into the air on the upwind side from horizontal stainless-steel tubes positioned about 150 mm above the canopy and following the growth of the crop (Figure 1). Concentrations were maintained within 90% target (495-605 µmol mol^{-1} air) for 93-98% of the time.

Pulses were grown in eight octagonal 'rings' in a randomised block design with four blocks. Within each block, there were one ambient (a[CO_2] ~ 390-400 µmol mol^{-1} air) and one elevated (e[CO_2] ~ 550 µmol mol^{-1} air) ring. From 2010 to 2012, peas were grown in rotation with wheat. Rings were 16 m in diameter, and split for a plus/minus supplemental irrigation treatment. Within each ring, cultivars of field peas were grown in sub-plots (4 by 1.4 m). In 2013, lentils were grown in 8-m rings, also split for a plus/minus supplemental irrigation treatment, in subplots of 2 rows (0.54 by 4 m). In 2014, lentils were grown in 4-m diameter rings and subplots of 4 rows (1 by 2 m) with no supplemental irrigation (Figure 1).

In addition, the SoilFACE array consists of eight 1-m deep bunkers dug in the soil (4 ambient and 4 elevated [CO_2]) with large intact soil cores (30 cm diameter x 100 cm deep) comprising three soil types: a Mallee Calcarosol, a Wimmera Vertosol and a High Rainfall Zone (HRZ) Chromosol (Figure 2) which permits the investigation of interactions between CO_2 level and soil type on crop growth.

Figure 1: 4-m lentil elevated [CO_2] ring in 2014

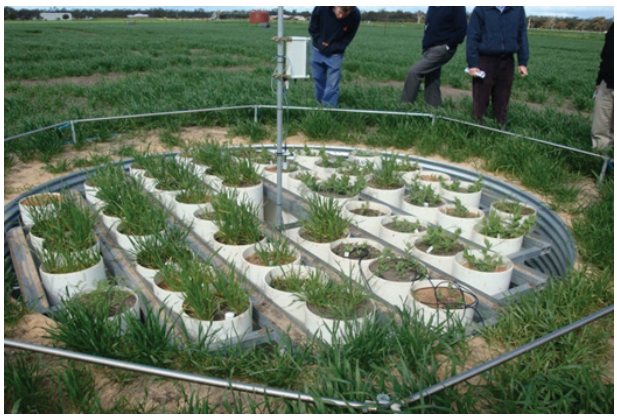

Figure 2: SoilFACE ring array

AGFACE 2010-2012: Field peas growth and grain yield

Five field pea cultivars were selected for their contrasting agronomic characteristics viz.leafiness, flowering time and duration, maturity, biomass accumulation, pod set and seed size. In particular, the cultivar PBA Hayman is a dual purpose, high biomass, small seeded cultivar (with low grain harvest index) representing an interesting contrast for evaluating potential sink limitations.

Averaged over the five cultivars, yields of field pea increased by 25% in 2010 (from 5.0 to 6.3 t ha^{-1}), 16% in 2011 (from 3.6 to 4.2 t ha^{-1}), and 39% in 2012 (from 2.6 to 3.6 t ha^{-1}) under e[CO_2]. There were no significant differences between cultivars in the yield response to e[CO_2] as illustrated in Figure 3 with cultivars aligning on or close to the line of average response. Similarly, e[CO_2] increased biomass at all growth stages observed but with no significant interaction between cultivar and CO_2 treatment..

However, there was genotypic variability in the grain N response to e[CO_2] in a three-way interaction with irrigation (Figure 4). Two cultivars (Bohatyr and Kaspa) consistently failed to maintain grain N concentrations under e[CO_2] regardless of water availability. By contrast, the cultivar Sturt maintained grain N concentration under rainfed conditions and PBA Twilight maintained grain N under supplemental irrigation. The dual-purpose cultivar PBA Hayman (small seeded and low harvest index) produced grains with higher N concentration and was better able to maintain grain N under e[CO_2] compared to other cultivars under both water regimes. Interestingly, the cultivars Sturt and PBA Twilight also differed in their yield response to irrigation with Sturt showing the greatest increase in yield and Twilight showing no response to the additional water. How some cultivars maintain grain N under e[CO_2] and contrasting irrigation treatments warrants further research.

SoilFACE 2009-2010: Field pea nitrogen fixation

Nitrogen fixation of field pea (line OZ0601) was assessed using the ^{15}N natural abundance technique with wheat as a reference species. Soil properties, especially soil nitrate supply, had a much greater effect on the amount of N fixed than e[CO_2] treatment, and significant differences were found in biomass, shoot N concentration, N uptake and N fixed in different soil types (Table 1).

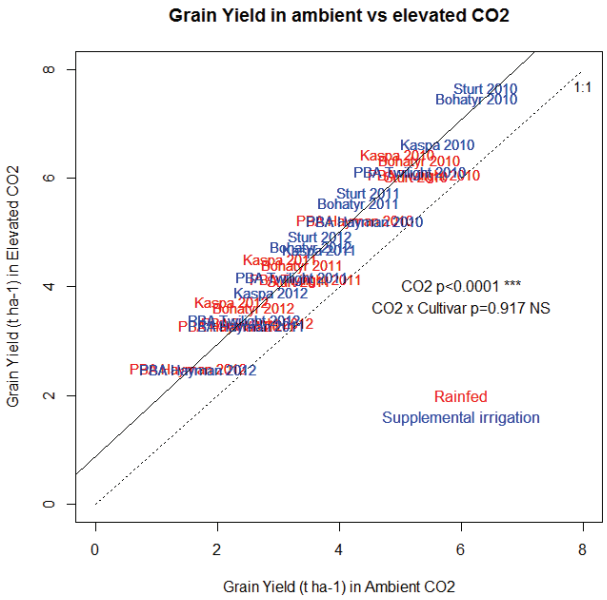

Figure 3: Lack of genotypic differences in the responsiveness of grain yield to e[CO_2] in field peas

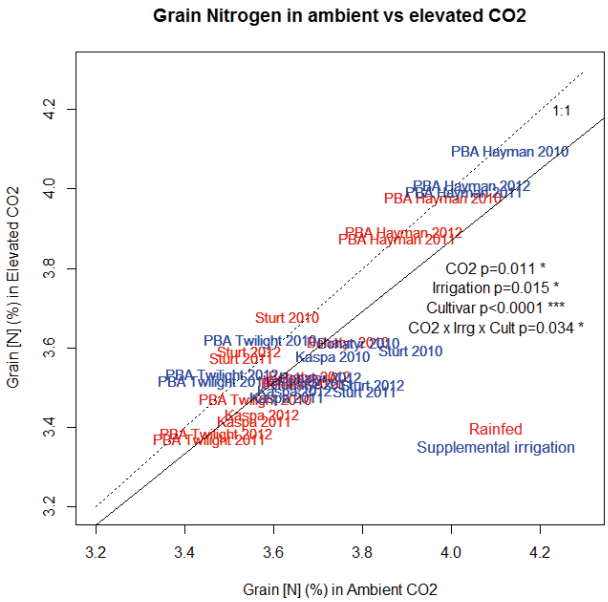

Figure 4: Genotypic differences in the response of grain nitrogen to e[CO_2] in field peas

The shoot biomass recorded in a Mallee Calcarosol in both 2009 and 2010 was significantly lower than that in the HRZ Chromosol but the proportion of legume N derived from the atmosphere (%Ndfa) was the opposite (e.g. 54.4% in the Calcarosol vs 9.9% in the Chromosol, when averaged across ambient and e[CO_2] in 2010). These differences in %Ndfa reflected the much higher soil nitrate levels recorded in the Chromosol at sowing, which can significantly inhibit N_2 fixation, compared to the Calcarosol.

Whereas there was no direct effect of e[CO_2] on the amount of N fixed in 2009 (which is the product of shoot N uptake and %Ndfa), in 2010 the overall amount of N fixed was more than doubled in the e[CO_2] treatment, but only when grown in the Vertosol; the Calcarosol and the Chromosol showed no stimulation with e[CO_2]. These results suggest that the effect of e[CO_2] on nitrogen fixation by field pea is not clear cut and that background environmental properties such as soil fertility will interact with e[CO_2] (see Armstrong et al 2015).

Table 1: Analysis of Variance for the SoilFACE experiment

	Dry matter (g/core)	Shoot N (%)	N uptake (g/core)	%Ndfa	N fixed (g/core)
	2009				
[CO_2]	NS	NS	NS	NS	NS
Soil type	**	*	*	NS	**
[CO_2] x Soil type	NS	NS	NS	NS	NS
	2010				
[CO_2]	0.06		NS	NS	NS
Soil type	***		***	***	***
[CO_2] x Soil type	*		0.06	NS	*

Significance levels: p>0.05 NS, 0.05>p>0.01 *, 0.01>p>0.001 **, p<0.001 ***

AGFACE 2013-2014: Lentils growth and grain yield

Six lentil cultivars were chosen for their genetic diversity and contrasting quality and agronomic characteristics differentiating in seed type, flowering time, maturity and vigour. The lentil line 05H010L-07HS3010 is a high biomass line that has a low harvest index.

Yields of lentil cultivars were increased by 34% in 2013 (from 2.7 t ha^{-1} in ambient to 3.6 t ha^{-1} under e[CO_2]) and by 147% in 2014 (from 0.38 t ha^{-1} in ambient to 0.94 t ha^{-1} under e[CO_2]), which suggests an ameliorating effect of e[CO_2] under severe drought terminal stress in the 2014 season. Cultivars differences were not significant (p=0.13 in 2013 and p=0.10 in 2014), but PBA Ace and PBA Jumbo tended to be higher yielding while 05H010L-07HS3010 tended to be consistently lower (Figure 5). Once again, we could not detect any significant differences in yield responsiveness to e[CO_2] between cultivars.

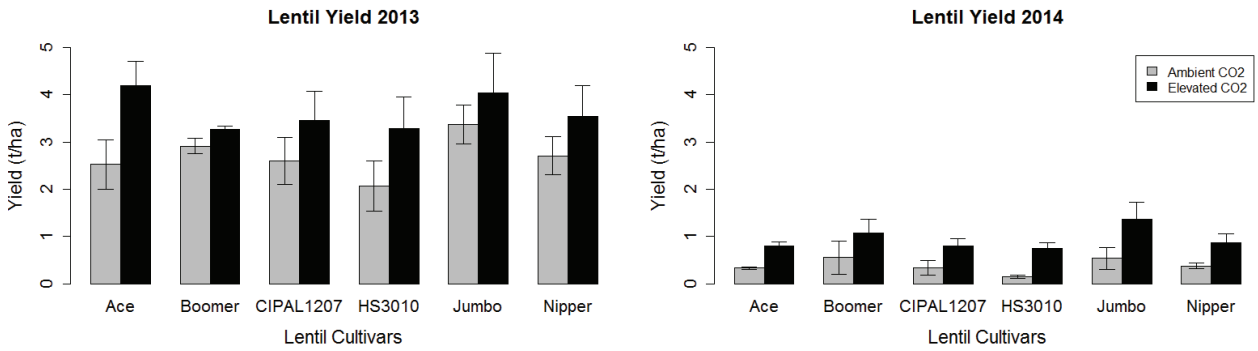

Figure 5: Grain yield in six lentil cultivars grown in AGFACE (2013-2014)

Current experimentation

In 2014, the cultivar PBA Ace and the lentil line 05H010L-07HS3010 were subjected to a 3-day heat shock under closed-top chambers with temperature raised to 40ºC during the day. These same plots were also equipped with mini-rhizotrons to scan images of the root system throughout the season. Preliminary results suggest that the heat shock has increased yields slightly from 0.51 to 0.65 t ha^{-1}. We also found cultivar differences in rooting depth, with 05H010L-07HS3010 reaching deeper layers faster while we could not find roots below 50 cm in PBA Ace. In addition, e[CO_2] increased root growth at all layers and particularly so in the 37.5 to 50 cm layer. These measurements will be collected again in the 2015 season.

Conclusion

Clearly, eCO_2 should increase yields of pulse crops in the absence of temperature increases. In very dry years, eCO_2 may make the difference between a commercial crop failure and a crop worth harvesting. However, we have also noted potential decreases in leaf and grain N and there genotypic variability for such traits provides the potential for better adapted varieties via breeding. While the amount of N fixed is increased through greater biomass accumulation under eCO_2, the proportion of N derived from the atmosphere remains similar, with soil type and soil N content appearing to have more effect on fixation.

Acknowledgements

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Using field-based Canopy EvapoTranspiration and Assimilation (CETA) chambers to assess the impact of climate change on early cotton growth

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Abstract
Changes in temperature, CO_2, and precipitation under the scenarios of climate change present a challenge to crop production, and may have significant impacts on the yield of cotton (*Gossypium hirsutum* L.). Understanding the implications of varied environmental conditions for agricultural crops is critical for developing cropping systems resilient to stresses induced by climate change. The aim of this study was to investigate the impacts of increased atmospheric [CO_2] on the growth of field-grown cotton in high-input/high-yielding Australian production systems. Canopy EvapoTranspiration and Assimilation (CETA) chambers were used to elevate atmospheric [CO_2] in the field. Cotton plants were grown under CETA chambers at higher temperatures (on average 4°C warmer) either at ambient [CO_2] (C_A: 400 ppm) or elevated [CO_2] (C_E: 650 ppm) from 44 days after planting (DAP) until 72 DAP (28 days total). The CETA chambers were a successful method of increasing atmospheric [CO_2] of field-grown cotton. Elevated [CO_2] increased early stage biomass by 67% of well-watered, field-grown cotton. Data from this study contributes information on the possible impact of climate change on crop production and thus may shape management decisions for crop production in future environments by providing information for crop simulation models.

Key words
Elevated [CO_2], temperature, *Gossypium hirsutum*, greenhouse gas

Introduction
Current projections for climate change indicate that Australia can expect more heatwaves, changes in rainfall distribution, an increase in the intensity of droughts, and small decreases in relative humidity (Whetton and Power, 2007). Changes in temperature, CO_2 and precipitation under the scenarios of climate change present a challenge to crop production, and may have significant impacts on the growth of cotton (*Gossypium hirsutum* L.). Understanding the implications of varied environmental conditions for agricultural crops is critical for developing cropping systems resilient to stresses induced by climate change. The global atmospheric [CO_2] has increased from pre-industrial value of about 280 ppm to 400 ppm in 2013 (CSIRO and Bureau of Meteorology, 2012, IPCC, 2013), and will continue to rise in the future, affecting plant physiology and growth. Elevated atmospheric [CO_2] generally stimulates photosynthesis, leading to increased crop growth and yield, especially in C_3 species.

A range of experimental systems, including environmental chambers, glasshouses, Soil-Plant-Atmosphere Research (SPAR) units, open-top chambers (OTC) and Free Air CO_2 Enrichment (FACE) facilities, have been developed to expose plants to elevated atmospheric [CO_2]. In controlled environmental chambers and glasshouses, individual plants are typically grown in pots, and light, water, humidity and nutrients are controlled. Therefore, there are often higher levels of environmental control than in field conditions, but such facilities may restrict root growth, which can negatively influence photosynthetic capacity, shoot growth and harvestable yield potential, and thus reduce the response to CO_2 stimulation (Ainsworth and McGrath, 2010, Arp, 1991). FACE experiments allow the exposure of plants to elevated [CO_2] under natural and fully open-air conditions. However, limitations of FACE systems include difficulty in controlling air temperature, water inputs, as well as cost (Kimball et al., 1997).

Canopy EvapoTranspiration and Assimilation (CETA) chambers are relatively portable, open systems that have been used to measure canopy gas exchange of pot-grown and field-grown cotton plants in the U.S. (Baker *et al*., 2014, Baker *et al*., 2009). This research investigates the use of CETA chambers as a method of imposing CO_2 treatments in field-based studies, and explores the effect of CO_2 enrichment on growth

characteristics of field-grown cotton. This paper presents research that aims to provide additional knowledge on the degree of climate change impacts on field-grown cotton in high input/high yielding Australian cotton systems.

Methods

A field experiment was conducted at Narrabri, NSW Australia during the 2012-2013 cotton growing season. The transgenic cotton variety Sicot 71 BRF [Bollgard II® Roundup Ready Flex®] (Stiller, 2008) was planted on 19th February 2013. The plots were prepared according to current production methods and plants were well-fertilised; however, sowing time of cotton was late in the season to avoid extremely high temperatures inside the chambers and to better simulate early season growing conditions.

Canopy EvapoTranspiration and Assimilation (CETA) chambers used were similar to the chambers described by Baker et al. (2009), and modified to allow for greater control of [CO_2] inside the chamber according to Baker et al. (2014). The chambers were 0.75 m x 1 m and 1 m in height. Transparent lexan (GE, Polymershapes, Coppell, TX) was used for the chamber walls, which reduced photosynthetically active radiation (PAR) by approximately 13% (Baker et al., 2014). Six aluminium bases were inserted approximately 5 cm into the ground. CETA chambers were set on top of four of the six bases and the remaining two were reference plots without either chambers or elevated [CO_2] (C_c treatment). Two chambers were ambient atmospheric [CO_2] (C_A treatment) and CO_2 gas was injected into the remaining two chambers and maintained at 650 ppm (C_E treatment). [CO_2] inside each of the chambers was recorded using a datalogger CR-3000 (Campbell Scientific Inc, Logan, UT). Temperature and relative humidity were not controlled, but were measured using a Tiny Tag Ultra (Gemini Data Loggers, West Sussex, UK) sensor. Plants were grown inside the CETA chambers for 28 days. Chambers were set up over the plants on 3rd April 2013 (43 DAP). CO_2 was injected into chambers from 4th April 2013 (44 DAP) until the 1st May 2013 (71 DAP).

Plants from each of the three treatments were harvested on 2nd May 2013 (72 DAP) and processed for biomass. Each plant was processed individually for height, nodes, total biomass, and leaf area. Samples were oven-dried at 80°C for 7 days and weighed. These data were analysed by residual maximum likelihood (REML) using Genstat version 16. Data were assessed at a P=0.1 level of significance.

Results

Chamber environment

The environment inside the chambers (C_A and C_E) varied with external field conditions. Daily air temperature was on average 4°C warmer inside the chamber than outside and at times was higher in C_E than C_A (Figure 1a). Mean daily relative humidity was on average 7.5 ± 0.77 % drier inside the chambers than outside (Figure 1b). Mean daily [CO_2] inside the C_A chambers was consistent over the experimental period, averaging 387 ± 0.8 ppm [CO_2] (Figure 1c). Mean daily [CO_2] inside the C_E chambers was more variable averaging 626 ± 6.8 ppm [CO_2], but consistently at least 200 ppm higher than C_A chambers.

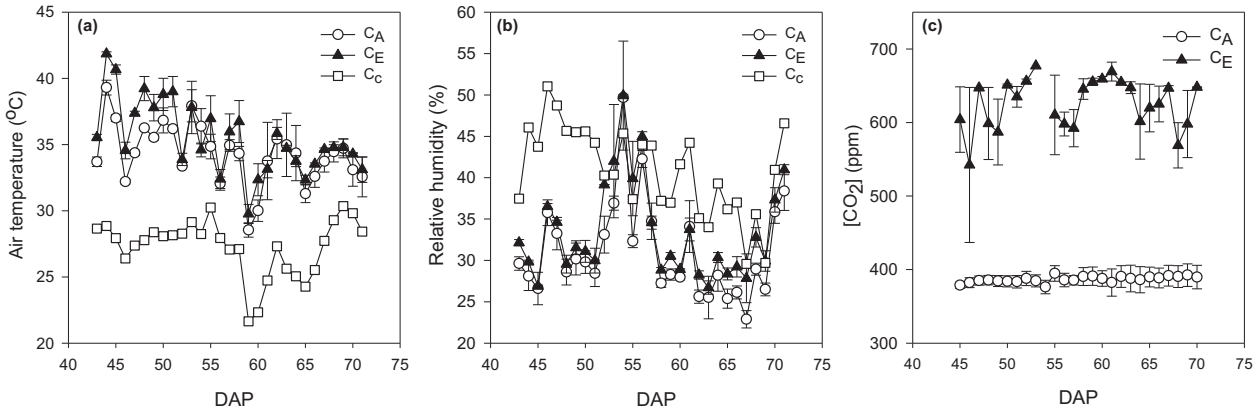

Figure 1: Average daily (a) air temperature, (b) relative humidity and (c) [CO2] from 8 am – 6 pm for ambient CO2 (CA, circle), elevated CO2 (CE, triangle) and control (Cc, square) for 43 – 71 DAP. Values represent mean ± SE of two chambers (sample size of one in the control treatment). Target [CO2] was 650 ppm, data range between 300 – 800 ppm with a gap in data at 54 DAP due to malfunction of data-loggers (panel c).

Plant growth and biomass

C_E increased vegetative biomass of cotton by 67% compared with the C_A treatment; however C_E did not increase fruit biomass compared with C_A (Table 1). Cotton grown at C_E had 51% greater leaf area and was 17% taller than plants grown at C_A, but there was no significant difference in the number of nodes (Table 1). Despite warmer air temperatures inside the chambers (Figure 1), there was no significant difference in biomass, leaf area or the number of nodes between the C_c and C_A treatments; however, C_A increased height by 30% compared with C_c (Table 1).

Table 1: Treatment means, standard errors (SE) and F-values for vegetative biomass, fruit biomass, leaf area, height and nodes for plants grown with no chamber (C_c), ambient chamber (C_A) or elevated chamber (C_E). † represents significance at P<0.1, * represents significance at P<0.05, ** represents significance at P<0.01 and * represents significance at P<0.001. Values in bold represent significant difference at P<0.1.**

Variable	C_C		C_A		C_E		F-value	
	Mean	SE	Mean	SE	Mean	SE	C_C compared with C_A	C_A compared with C_E
Vegetative biomass (g plant^{-1})	6.6	0.44	7.0	0.42	11.8	0.95	0.556	0.039*
Fruit biomass (g plant^{-1})	0.2	0.03	0.4	0.06	0.6	0.09	0.296	0.251
Leaf area (cm^2 plant^{-1})	388.0	22.64	445.6	25.05	673.5	47.10	0.220	0.040*
Height (cm plant^{-1})	34.2	0.89	44.4	1.44	51.9	1.44	0.001***	0.061†
Nodes (plant^{-1})	10.8	0.25	11.2	0.29	12.1	0.09	0.296	0.251

Discussion

CETA chambers were successfully used to elevate atmospheric [CO_2] of field grown cotton. Advantages of these systems are that they are portable and do not require as much infrastructure and CO_2 as larger-scale free air carbon dioxide enrichment (FACE) experiments. In addition, plants were grown in the field, thereby better capturing crop and canopy effects, and eliminating pot effects (Thomas and Strain, 1991). However, some of the limitations of these chambers include warmer air temperatures and substantially lower relative humidity, and thus higher atmospheric vapour pressure deficit (VPD_a) which affects gas exchange in cotton (Conaty et al., 2014, Duursma et al., 2013). Therefore, CETA chambers allow for the study of interactive effects of projected climate change, although it is not possible to differentiate temperature and VPD_a effects. For these reasons, comparisons for the effects of elevated atmospheric [CO_2] on cotton can only be made between C_A and C_E chamber treatments.

Our data showed that C_E increased vegetative biomass by 67%, whereas the increase in biomass due to elevated [CO_2] was 37% in FACE experiments (Mauney et al., 1994). However, the FACE experiment was conducted over a longer period of time (C_E for 144 days compared with 28 days), thus early growth benefits may be reduced with an extended period of time. In addition, differences in temperature, light and VPD may have also had an effect. Our data also showed large increases in leaf area with C_E, which increases area for leaf photosynthesis and transpiration, and thus may contribute to greater plant-level water use. Despite large increases in vegetative biomass, our data indicated that fruit biomass may not be significantly increased by C_E. Reddy et al. (1995) also found that floral initiation of cotton grown over a similar timeframe to this study, was not influenced by elevated [CO_2] (700 ppm compared with 350 ppm [CO_2]). However, studies of later stage growth, development and fibre quality are necessary before these conclusions can be drawn.

Conclusions

This study has highlighted that CETA chambers are a successful method of increasing atmospheric [CO_2] of field-grown cotton, however limitations of warmer temperatures, and altered humidity and VPD_a limit the comparison and interpretation of some of the data. This study also showed that early season biomass and leaf area of field-grown cotton were greatly increased with C_E which could potentially increase plant-level

water use. However, this study did not indicate that increases in vegetative biomass with elevated [CO_2] were reflected in fruit biomass and consequently yield. Further research is needed to assess the impact of C_E over the full length of a season, to quantify plant water use of cotton grown in projected future environments and to provide information for crop simulation models.

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Soil type influences N_2 fixation in fieldpeas more than elevated CO_2

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Little is known about how elevated atmospheric carbon dioxide (eCO_2) affects pulse growth and nitrogen (N) fixation in medium rainfall dryland cropping systems. We examined the growth and N_2 fixation of field-peas (Pisum sativa cv. OZ0601) in the SoilFACE array at Horsham (annual rainfall 420 mm). Fieldpeas were grown under either ambient (ca. 390 ppm) or elevated CO_2 (550 ppm) in large (30 cm width x 100 cm long) intact soil cores placed in replicated bunkers in the ground. The intact cores, which maintain the physical and chemical integrity of the soil profile, were collected from 3 soil types: a Calcarosol, a Vertosol and a Chromosol. Soil N concentration of the 3 soils was Chromosol > Vertosol > Calcarosol. The fieldpeas were grown in rotation with wheat (*Triticum aestivum* cv. Yipti) over 2 seasons and N fixation assessed using the natural abundance method. In 2010, the growth and grain yield of fieldpea was increased by eCO_2 and affected by soil type. Neither factor however affected the proportion of plant N derived from N_2 fixation (%Ndfa), although there was a significant interaction between soil type and eCO_2 on the amount of N fixed. In 2011, soil type significantly affected growth, yield and %Ndfa of field pea but eCO_2 had no effect. %Ndfa was strongly related to the amount of NO_3-N in the profile at sowing. N_2 fixation in fieldpeas is, at least in the initial phase of CO_2 treatment, influenced more by soil type (soil N availability) than eCO_2.

Key words
SoilFACE, elevated CO2, N_2 fixation

Introduction

Future increases in atmospheric CO_2 offer the chance to greatly increase plant productivity via effects on a range of plant physiological processes including photosynthesis and water relations (Kimball *et al*. 2002). These increases however are contingent on adequate supplies of available nitrogen (N) (Newton *et al*. 2007). The productivity of Australian cropping systems is heavily reliant on soil N supply, with a large proportion of this N traditionally coming from biological fixed N including that from grain legumes (Angus 2001, Evans et al. 2001). The rate of N_2 fixed, and the value of the N derived from legumes to subsequent crops, can vary markedly with seasonal conditions and site/soil (Kirkegaard *et al*. 2008).

Growth stimulation by elevated CO_2 (eCO_2) is generally greater in legumes than non-legumes, probably as a result of maintaining high leaf N status (Kimball *et al*. 2002). FACE (Free Air Carbon Dioxide Enrichment) studies have revealed many factors operating in the open field situation that cannot be identified in other types of studies (Leakey et al. 2009). There have been very few studies however (other than for soybeans) of the response of grain legumes to eCO_2 in the field (Rogers et al. 2009). In this paper we report an experiment that examined the effect of eCO_2 on the growth and N_2 fixation of a pulse (field pea) grown in rotation with wheat in three different soil types in the SoilFACE array.

Methods

SoilFACE, located near Horsham (36°45'S, 142°06'E; 127m elevation) is a FACE array based on the use large intact cores (30 cm diameter x 100 cm deep cased in a PVC sleeve), that maintain the physicochemical integrity of the soil profile, to assess interactions between soil type and eCO_2 on crop growth. Cores were collected from the Victorian Mallee (Calcarosol), Wimmera (Vertosol) and High Rainfall Zone (Chromosol) (Table 1) with experimentation commencing in 2009. The cores were placed in 8 bunkers sunk into the ground (the top of the cores are at ground level). Four bunkers are maintained at ambient CO_2 (ca. 390 ppm) whilst four are maintained at 550 ppm atmospheric CO_2 (eCO_2) as per Mollar et al. (2009). The experimental design consisted of field pea (cv. OZ00601) grown in rotation with wheat (cv. Yipti) x 3 soil types x eCO_2/ambient CO_2 x 4 reps in a split plot design.

At peak flowering one intact core in each treatment was cut at ground level, the material dried at 70°C, weighed and ground. Total N and ^{15}N enrichment was determined by isotope ratio mass spectrometry (IRMS)

(continuous flow Isotope Cube (Elementar, Germany) coupled with a continuous flow mass spectrometer (Isoprime, United Kingdom) utilizing Dumas flash combustion. The proportion of N derived from fixation was determined using the natural abundance technique (Peoples *et al*. 1989) using wheat collected from cores of the same soil type as a reference plant. At grain maturity plants were cut at ground level prior to drying, grain separated by threshing and total N content of the ground material determined by Leco™ analyser (St Joseph, MI, USA). A basal application of P (single superphosphate equivalent to 15 kg P/ha) was sown with the seed. Prior to sowing each year, soil was collected at 0-10, 10-20, 20-30, 30-50, 50-70, 80-95 cm using a thin walled tube (42 mm cutting tip) and gravimetric soil water (following drying at 105°C) and NO_3-N measured by extraction (1:10) in 2 M KCl followed by colorimetric analysis (Searle 1984) on a Flow Injection Analyser. Annual and growing season rainfall (April – November: GSR) at the site was 559 and 330 mm in 2010 and 507 and 250 mm in 2011, respectively.

Table 1: Characteristics of 3 soils used in SoilFACE

Soil	pH ($CaCl_2$) 0-10 cm	EC(1:5) 80-100 cm (dS/m)	ESP 80-100 cm (%)	Total N 0-10 cm (%)	Total C 0-10 cm (%)
Chromosol	4.5	0.16	4.3	0.40	4.66
Vertosol	7.7	1.85	20.0	0.08	1.10
Calcarosol	5.9	0.53	7.5	0.05	0.64

Results

In 2010 (second season after CO_2 treatment commenced), eCO_2 stimulated the growth at flowering and maturity, early N content and grain yield of field pea (Table 2). Dry mater production and grain yield were strong affected by soil type in the general order Vertosol > Chromosol > Calcarosol. The proportion of plant N derived from N_2 fixation at flowering was significantly affected by soil type (lowest on the Chromosol and highest on the Vertosol and Calcarosol soils) but CO_2 treatment had no effect. As a consequence, there was a significant interaction between the CO_2 and soil type on the amount of N fixed (kg/ha) at flowering in the eCO_2 Vertosol cores being greater than ambient CO_2 cores, which in turn were higher than that in the Chromosol soil, regardless of CO_2 treatment. In 2011, the relative growth and grain yield of fieldpeas in the Calcarosol cores increased especially compared to the Chromosol cores, to be no different than the Vertosol. CO_2 treatment however had no effect on the growth, yield or rate of N_2 fixation of fieldpeas.

The large differences in background soil N and C at the commencement of SoilFACE (Table 1) were reflected in the amount of soil NO_3-N (0-90 cm) measured at sowing in 2010 with the Chromosol cores having much higher NO_3-N (146 kg/ha) than the Vertosol (64 kg/ha), which in turn was higher than the Calcarosol soil (24 kg/ha) (data not presented). Neither CO_2 nor previous crop had any significant effect on NO_3-N. In 2011, (3rd season of experimentation), this effect on NO_3-N at sowing persisted with Chromosol > Vertosol > Calcarosol and generally no effect of CO_2 or previous crop: the exception was that the large amount of NO_3-N recorded in eCO_2 Chromosol cores following wheat in 2010. These differences in soil NO_3-N were strongly related ($R^2 = 0.73$) to the %Ndfa of the field peas (Figure 1).

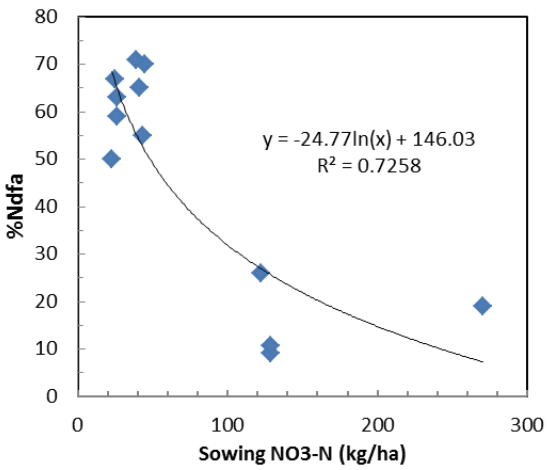

Figure 1: Relationship between profile NO_3-N at sowing and the proportion of legume N derived from N_2 fixation (%Ndfa) of field peas (pooled across years, soil and CO_2 treatments).

Table 2: Influence of CO_2 (ambient and eCO_2) and soil (Calcarosol, Vertosol and Chromosol) on the proportion of N derived from N_2 fixation and the amount of N fixed at flowering and the total dry matter, grain yield and N uptake of field pea at maturity in SoilFACE (2010 and 2011)

CO_2	Flower DM (g/core)	Flower N Content (g/core)	%Ndfa	N fixed (g/ core)	Maturity DM (g/core)	Grain yield (g/core)	Maturity N (mg/ core)
2010							
Calcarosol							
Amb	32.6	710	49.9	379	46.9	25.3	nd
eCO_2	28.1	580	58.9	334	49.7	28.5	nd
Vertosol							
Amb	60.1	1330	55.0	451	75.2	39.5	nd
eCO_2	96.0	1950	64.6	995	91.0	48.7	nd
Chromosol							
Amb	47.1	1020	9.1	81	51.0	23.4	nd
eCO_2	57.7	960	10.7	63	66.2	32.6	nd
l.s.d. (5%)	Soil x CO_2 = 21.1	CO_2 ns Soil = 339	Soil = 29.7	Soil x CO_2 = 347	CO_2 = 7.8 Soil = 9.5	CO_2=3.95 Soil = 4.9	nd
2011							
Calcarosol							
Amb	52.9	1112	69.9	780	58.2	30.3	1256
eCO_2	51.9	1001	71.4	716	73.6	37.8	1334
Vertosol							
Amb	60.6	1388	62.6	858	70.9	35.9	1392
eCO_2	50.3	1075	67.0	717	80.9	43.7	1802
Chromosol							
Amb	34.0	699	25.6	138	53.3	26.2	973
eCO_2	26.2	555	18.6	108	60.2	29.2	1068
l.s.d. (5%)	Soil = 14.6	Soil = 307	Soil = 27.2	Soil = 343	Soil = 10.1	Soil = 3.9	Soil = 387

Discussion

Any stimulatory effect of eCO_2 on plant production is strongly related to adequate N supplies (Leakey et al. 2009). This relationship between N supply and eCO_2 will most likely be even more important in the dryland cropping systems of southern Australia as N inputs form a significant proportion of grain grower's variable cost inputs, and N derived from N_2 fixation provides a major proportion of N supplies in many cases. In this study we found that effect of eCO_2 on the dry matter and yield of field peas varied with season, being more important in 2010 when soil water availability was much above long-term average than in 2011.

However eCO_2 had no effect on %Ndfa in either year, although it did increase the amount of N fixed in 2010 as a result of the greater dry matter produced. In contrast, soil type had a much greater effect on growth and yield as well as %Ndfa in both 2010 and 2011. This result is in general agreement with other studies of N dynamics of legumes under eCO_2 that found that whereas the amount of N fixed increases by an average of 38% under eCO_2, the change in %Ndfa is non-significant (Lam *et al*. 2012). Legume N_2 fixation is very sensitive to soil nitrate concentration (Herridge et al. 1998) and in our study we found a strong negative relationship between NO_3-N at sowing and %Ndfa, that appeared to override eCO_2 treatment (Figure 1).

There is a general conclusion that, at least in grasslands, the availability of N for plant growth declines with time under eCO_2 (Progressive Nitrogen Limitation) (Newton *et al*. 2010). Our study found that eCO_2 had little consistent measurably effect on %Ndfa whereas soil type (and especially background N content) had a major impact during the first 3 years after CO_2 treatment commenced. In soils like the Wimmera Vertosol where the background C and N content is relatively low after decades of continuous cropping, even small changes in N_2 fixation rates of pulses may have significant impacts on productivity as the relative value of N derived from legumes to subsequent crops may be reduced in future environments with eCO_2 (Lam et al. 2013).

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Reflectance and fluorescence measurements for wheat traits under elevated CO_2

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Abstract
The concentration of CO_2 continues to rise in the atmosphere and is expected to increase from 400 ppm currently to 550 ppm by 2050. Research has shown that this can increase yields due to the "fertilisation effect" of CO_2, but leaf nitrogen and grain protein levels in cereals reduce under elevated CO_2 (eCO_2). Despite results from Australian and international research showing a consistent decline in grain protein under eCO_2, there is currently no solution to slowing or reversing this decrease. Experiments during 2014 at the Australian Grains Free Air CO_2 Environment (AGFACE) facility tested lines of wheat with traits purported to improve nitrogen efficiencies and other characteristics that may contribute to resisting or reversing the decline in grain protein. As part of the research, non-destructive proximal measurements were assessed to detect trait differences between ambient and eCO_2 environments. Active optical sensing (Crop Circle 210) was used to assess differences in the canopy cover. A hand-held field fluorometer (FORCE-A Multiplex 3.6) was used to measure fluorescence excitation and emission ratios at the canopy level. NDVI time series from the active optical sensor responded to the differences between rainfed and well watered plots, but ANOVA results near anthesis were not significant for the CO_2 effect. The fluorometer index NBI_G was found to be positively, linearly related to leaf %N from analysis of plant samples ($R^2 = 0.69$) with a standard error of 0.32 %N. *In situ* fluorometer NBI_G measurements were significant for both water and CO_2 effects on one date following anthesis.

Key Words
Phenotyping, proximal sensing, elevated CO^2, fluorometer, nitrogen use efficiency

Introduction
Leaf nitrogen and grain protein levels in cereals have been shown to reduce under eCO_2 (Myers et al. 2014; Panozzo *et al*. 2014). Experiments at the Australian Grains Free Air CO_2 Environment (AGFACE) facility (Mollah *et al*. 2009) in 2014 tested lines of wheat with traits purported to improve nitrogen efficiencies and other characteristics that may contribute to resisting or reversing the decline in grain protein. In addition to plant sampling for dry matter and nitrogen concentration near anthesis, proximal sensors were used to monitor treatment differences. Active optical sensors measure the reflectance of canopy in the red and near infrared regions. While these measurements are related to chlorophyll concentration and biomass, the measurements most closely relate to fractional green cover (Perry *et al*. 2012), and can be used to track relative growth differences. Fluorescence measurements with active optical sensors (Agati *et al*. 2011) have been shown to be useful for measurements of leaf chlorophyll and flavonoids and as an indicator of leaf nitrogen (Agati *et al*. 2013). In this paper we describe the results from the non-destructive measurements with respect to testing the effectiveness of the technologies to detect trait differences.

Methods
Field site and sampling
The AGFACE facility is located near Horsham, VIC (142° 06' E longitude, 36° 44' S latitude). Details of the site, climate, and CO_2 dispersion mechanism can be found in (Mollah et al. 2009). In this paper we use the AGFACE 2014 wheat plots; treatment factors considered are CO_2 (elevated to 550 ppm and ambient, 400 ppm), four wheat varieties, and two differences in seasonal water inputs. The water input differences were rainfed and supplemental irrigation plots with 189 mm and 399 mm for the season, respectively. Wheat varieties Gladius and Wyalcatchem were selected for traits related to improved nitrogen use efficiency, and these were grown under rainfed conditions. The varieties Scout and Yitpi were planted in the well watered plots. Fluorometer readings were made in the lab on the fresh intact leaves for all treatments and reps (N = 72) prior to preparation for leaf N analysis.

Sensors
An active optical canopy sensor (CC210, Holland Scientific, Lincoln NE USA) was used to characterize the fraction of canopy cover. Weekly measurements were made over each plot. Sensor readings of NDVI were averaged for each plot and acquisition date. A handheld active light fluorometer (Multiplex 3.6, Force A, Orsay Cedex FRA) with four excitation bands (UV, blue, green, and red) and three detection bands (yellow, red and far red) was used both for field plots and fresh leaves cut for biomass. The fluorometer measurements resulted in a suite of indices from various combinations of the activation and detection wavelengths used (e.g., Gozlen *et al*. 2010). Four measurements per plot (*in situ*) were made on three dates; the four measurements were averaged for each plot. Measurements were also made on fresh stacked leaves from biomass cuts prior to processing for %N analysis.

Results
The active optical measurements made through the season form time series for the eight combinations of variety and CO_2 (Fig. 1). These time series show that while the variety Wyalcatchem initially had higher fractional green cover than the other varieties, the varieties in well watered plots (Scout and Yitpi) overtake the growth following GS30. For some of the growing season, the NDVI values for the eCO_2 plots appear to be slightly lower than the aCO_2 plots. In particular, the difference is observed for Scout and Yitpi (well watered plots) after 20 Aug. 2014 (GS34), and for Gladius (rainfed).

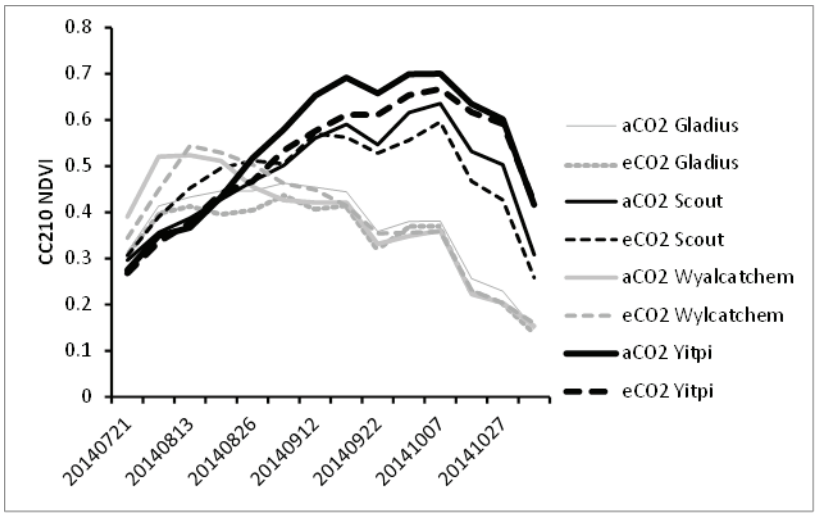

Fig. 1. NDVI values from the active optical sensor, tracking fractional green cover through time for the rainfed NUE plots (Gladius and Wyalcatchem) and the well watered plots (Scout and Yitpi).

A suite of the fluorometer indices was evaluated against measured leaf %N from the GS65 plant sampling. The nitrogen index 'NBI_G' (Agati *et al*. 2013) was found to have the highest correlation to leaf %N, with a positive, linear relationship ($R^2 = 0.69$) with a standard error of 0.32 %N. The index is computed by the instrument as the ratio of the infrared fluorescence excited with UV light, divided by the red fluorescence excited with green light. Based on these results, this index was selected for use to assess differences in plot canopy nitrogen. The GS65 sampling confirms lower leaf %N for values for elevated CO_2 plots relative to ambient plots, for both rainfed and well watered plots (Fig. 2a). The fluorometer measurements of NBI_G, taken on the fresh samples prior to processing, also indicate this trend (Fig. 2b). However, active optical measurements made on the plots just prior to sampling indicate differences between variety (and therefore water supply) but not CO2 effects (Fig. 2c). ANOVA results indicate that the difference in CO_2 are significant ($F_{pr} < 0.001$) for both the leaf %N and the fluorometer measurements made on fresh leaf samples, but not the active optical measurements (Table 1). The fluorometer measurements made in the field plots (*in situ*) for the three dates are shown in Fig. 2. Note that measurements made on 22 Sept 2014 (~GS50) do not show the same trends in leaf N (Fig. 2d). The differences in response with CO_2 is more evident in the 7 Oct measurements (Fig. 2e), and more obviously for the 15 Oct (Fig. 2f). The ANOVA results (Table 1) indicate the difference in CO_2 was not significant for the 7 Oct measurements, but was for the 15 Oct ($F_{pr} = 0.03$).

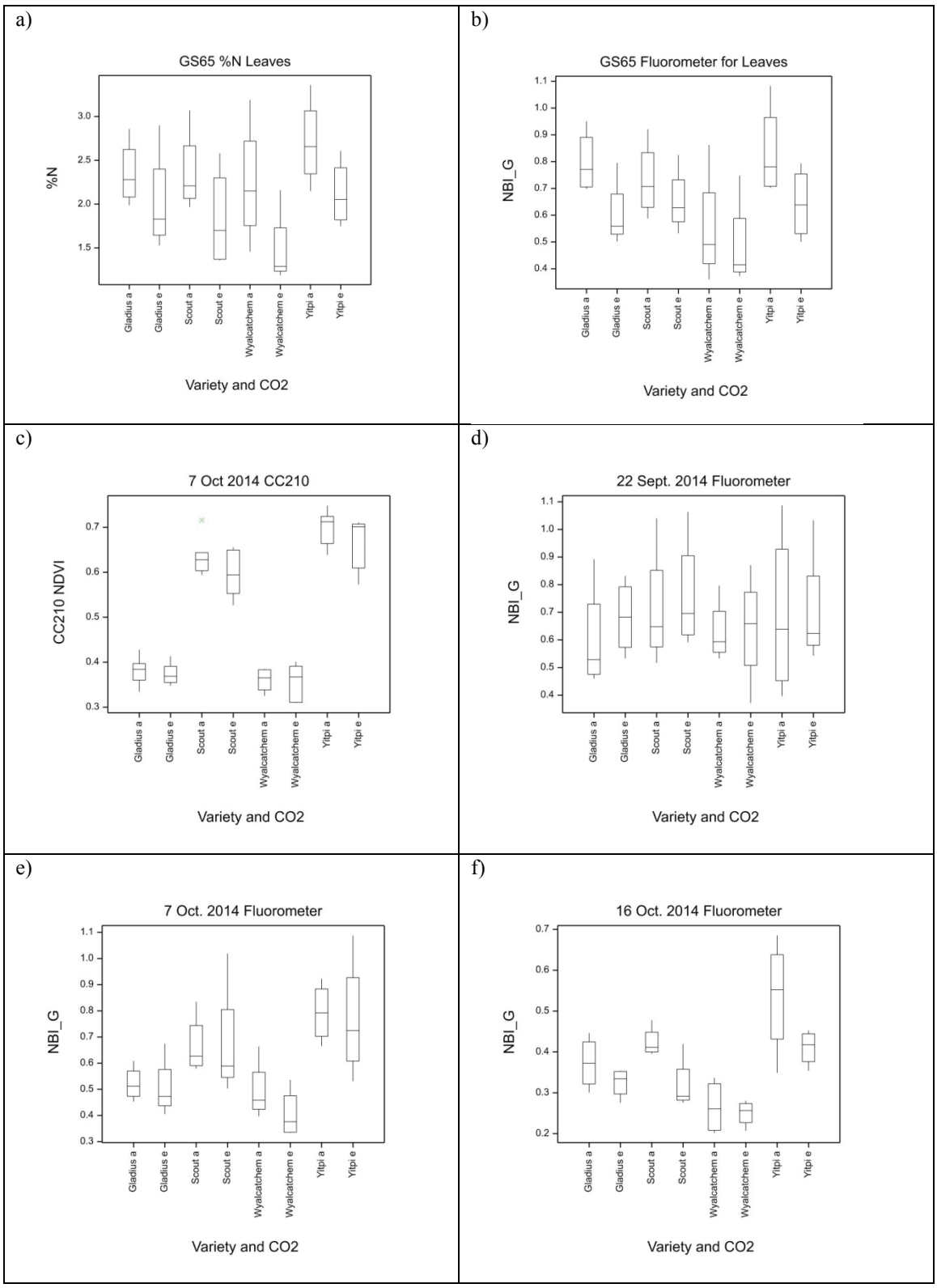

Fig. 2. Box plots showing the median, and +/- 25th percentile of various measurements by variety and CO_2. Gladius and Wyalcatchem were maintained on rainfed conditions (189 mm water for the season), while Scout and Yitpi were well irrigated (399 mm water for the season). CO_2 treatments are indicated by 'a' for ambient and 'e' for elevated (550 ppm). The measurements are a) leaf N at anthesis, b) fluorometer NBI on fresh cut leaves at anthesis, c) *in situ* active optical measurements at anthesis, and *in situ* fluorometer NBI measures made d) ~GS50, e) GS65, and f) following GS65.

Table 1. ANOVA results for %N of leaves, CC210 NDVI and Fluorometer NBI_G with respect to CO_2 and treatments (variety).

	d.f.	Sum of Sq.	Mean Sq.	F	F pr.
%N Leaf at GS65					
CO_2	1	2.42550	2.42550	54.40	0.005*
Variety	3	1.24666	0.41555	8.00	0.001*
Fluorometer NBI_G leaf samples					
CO_2	1	0.139868	0.139868	58.21	0.005*
Variety	3	0.229842	0.076614	14.84	<.001*
CC210 in situ (7 Oct 2014)					
CO_2	1	0.005156	0.005156	3.87	0.188
Variety	3	0.978132	0.326044	232.75	<.001*
CC210 in situ (20 Oct 2014)					
CO_2	1	0.002161	0.002161	2.90	0.187
Variety	3	1.018313	0.339438	116.17	<.001*
Fluorometer NBI_G in situ (22 Sept 2014)					
CO_2	1	0.01205	0.01205	0.26	0.645
Variety	3	0.05667	0.01889	1.13	0.363
Fluorometer NBI_G in situ (7 Oct 2014)					
CO_2	1	0.007351	0.007351	0.77	0.446
Variety	3	0.538688	0.179563	31.39	<.001*
Fluorometer NBI_G in situ (16 Oct 2014)					
CO_2	1	0.042566	0.042566	15.64	0.029*
Variety	3	0.186626	0.062209	18.90	<.001*
*Sig. at 0.05					

Conclusion

While active optical measurements (NDVI) are useful for tracking plant growth through the season, the fluorometer NBI_G measurements look promising as an estimate of canopy N. These measurements of canopy N are needed for assessing eCO_2 effects on wheat, and NBI could be used to estimate plant %N directly in the field and as part of scientific research. As this was the first season to utilize this instrument, future measurements will be used to validate the relationship between NBI (and other indices) and leaf and plant %N from lab analysis. Given the initial results, weekly to bi-weekly fluorometer measurements in situ are recommended to track differences through the season and could reduce the need for chemical leaf analyses.

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Influence of nitrogen supply and variety on the grain yield and protein content of wheat under elevated carbon-dioxide

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Abstract
Previous research in Free Air CO_2 Enrichment (FACE) facilities has indicated a significant decline in grain protein levels of wheat grown under elevated carbon dioxide (eCO_2), raising the question whether nitrogen (N) management can be used to reverse this decline. Two experiments, one under controlled environment (CE) conditions, the other in a FACE array ("SoilFACE"), were conducted to examine the nature of interactions between genotype, N supply, eCO_2 (and soil type in SoilFACE) on grain yield and protein in wheat. The first experiment consisted of 9 wheat cultivars/lines by 3 rates of N application (corresponding to deficient, adequate and luxury) and either ambient (ca. 390 ppm) or eCO_2 (700 ppm). The cultivars tested putatively varied in aspects of 'nitrogen use efficiency' (NUE) and 'vigour': Gladius (low NUE), Wyalkatchem (high NUE), Mace (high NUE), Scout (high vigour), Yipti (low vigour), Spitfire (high protein), EGA Gregory (low protein/high yield), and two experimental lines varying in protein content (WB4-1-12 and WB4-1-16). Although there was a significant main effect for each of CO_2, variety and N on a range of physiological and morphological variables measured (although importantly not on either grain yield or protein) there was no significant interaction between CO_2 and variety. Increasing N rate increased grain number ($P < 0.05$) and this effect was greater under eCO_2. Increasing N rate tended ($P = 0.055$) to increase kernel weight at ambient CO_2 but had no significant effect at eCO_2. Results from SoilFACE generally verified those of the CE study, suggesting that there may be only limited opportunity to reverse grain protein decline under eCO_2 by 'genetic solutions'.

Key words
SoilFACE, nitrogen, nitrogen use efficiency

Introduction
One major concern for future increases in atmospheric CO_2 concentration (eCO_2) is consistent declines in grain protein found in both overseas (Högy et al 2013) and Australian (AGFACE- Australian Grains Free Air CO_2 Enrichment) studies (Fernando et al 2012). Grain protein is a critical market attribute for Australian wheat exports so strategies are needed to reverse this protein decline.

Two potential strategies for reversing protein decline under eCO_2 are identification of genetic variation for trait (and subsequent use in breeding programs) and nitrogen (N) management. Recent experimentation in Australian National Variety trials has indicated significant varietal variation in grain protein as well as from N management, although this relationship is also strongly linked to grain yield responses and soil water availability (McDonald 1989).This paper reports results of two experiments, one conducted under controlled environment conditions and the other under Free Air CO_2 Enrichment (FACE), that assessed interactions between wheat genotype, N supply and eCO_2. We tested the hypothesis that a combination of an appropriate cultivar when supplied with adequate N, will maintain grain protein whilst realising increased grain yield under eCO_2.

Methods
A controlled environment (CE) experiment was conducted in a naturally lighted glasshouse comprising 6 sealed units that were maintained at either ambient (390) or eCO_2 (700 ppm). The experimental design consisted of 9 wheat cultivars x 3 rates of N fertiliser application x either ambient or eCO_2 in a randomised complete block design with 3 replicates. The 9 wheat cultivars (or experimental lines) were selected on the basis of putative variations in aspects of N use efficiency, such as grain yield response at high N rate versus low N rate (NUE) using results of GRDC NVT field trials, and known differences in vigour or grain protein. Selected lines were Gladius (low NUE), Wyalkatchem (high NUE), Mace (High NUE), Spitfire (high protein), EGA Gregory (low protein/high yield), Scout (high vigour), Yipti (low vigour), WB4-1-12 and WB4-1-16. The three N rates were 0, 40 and 80 kg N/ha applied as a solution of NH_4NO_3 at the 2 leaf stage

(designed to represent full N response range). An additional 40 kg N/ha was applied to the 80 kg N/ha pots at stem elongation. Plants were grown in 180 mm square pots containing 5 kg of an N-deficient Vertosol soil. Basal nutrients (P, K, S, Cu, Zn, Mn, Mo and B) were applied to ensure that only N was limiting. Soil in the pots was maintained at field capacity by watering to weight twice weekly with reverse osmosis water. Six seeds per pot were sown in early June 2014 and then thinned to 4 at the 2 leaf stage. Plants were harvested at anthesis (GS 65 – decimal growth stage) and grain maturity (GS 92) before drying (60°C), weighing and processing. Tissue N was determined by Dumas combustion (Leco).

The field experiment was undertaken in SoilFACE, a FACE array based on the use of large intact cores (30 cm diameter x 100 cm deep cased in a PVC sleeve), that maintain the physicochemical integrity of the soil profile, to assess interactions between soil type and eCO_2 on crop growth. Cores were collected from the Victorian Mallee (Calcarosol), Wimmera (Vertosol) and High Rainfall Zone (Chromosol) (Table 1). The cores are placed in 8 bunkers (4M diameter) sunk into the ground (the top of the cores are at ground level). Four bunkers (replicates) are maintained at ambient (ca. 390 ppm) whilst four are maintained at 550 ppm atmospheric CO_2 (eCO_2) as per Mollah et al (2009). The experimental design consisted of 3 wheat varieties x 3 soil types x 2 levels of applied N (0, 75 kg N/ha) x 2 CO_2 levels x 4 reps (bunkers). The wheat varieties were Gladius, Wyalkatchem and Yipti. The N was topdressed (as granular urea) on 30 July. Monthly rainfall (April to November) was 42, 25, 35, 34, 11, 11, 7 and 17mm (total = 182 mm) compared to long-term average = 344 mm). Due to such low spring rainfall, supplementary irrigation (21mm/event) was applied to all cores on 5/9, 17/9, 19/9 and 3/10/2015. Wheat was sown on 4 June and harvesting commenced on 26 November. Plant samples were treated as per the CE experiment.

Table 1: Soil characteristics of 3 soils used in SoilFACE and profile (0-90 cm) soil nitrate (mg/core) and volumetric water (mm/core) prior to sowing in 2014.

Soil	pH ($CaCl_2$) 0-10 cm	EC(1:5) 80-100 cm (dS/m)	ESP 80-100 cm (%)	Total N 0-10 cm (%)	Total C 0-10 cm (%)	NO_3-N (mg/core)	Vol. H_2O (mm/core)
Chromosol	4.5	0.16	4.3	0.40	4.66	68	285
Vertosol	7.7	1.85	20.0	0.08	1.10	35	324
Calcarosol	5.9	0.53	7.5	0.05	0.64	34	179

Results

Under CE conditions, there was a significant main effect of CO_2, variety and N rate on a range of physiological and morphological variables measured (although not on grain yield) (Table 2). Highest protein content was recorded in Spitfire, WB4-1-12 and Wyalkatchem and lowest in Gregory and Mace (data not presented). There was however no interaction between CO_2 x variety, variety x cultivar and N x CO_2 (Table 2). Increasing N rate increased grain number ($P < 0.05$) and this effect was greater under eCO_2 whereas increasing N rate tended ($P = 0.055$) to increase kernel weight at ambient CO_2 but had no significant effect at eCO_2. Importantly, although there was a significant positive effect of N rate and variety on grain protein, eCO_2 had no significant effect nor did it interact with variety or N rate. There was a trend ($R^2 = 0.47$), when all varieties were pooled, for grain protein to decrease with increasing grain yield but there was no relationship ($R^2 = 0.15$) between grain protein and plant N uptake.

In SoilFACE, where experimentation was undertaken in large intact cores that varied markedly in background N supply but water availability was restricted, eCO_2 significantly increased grain yield of all varieties tested (average of 33%), reduced grain protein content (from 10.3 to 9.0%) and had no effect on total N uptake (Table 3). Gladius produced the lowest grain yield and total N uptake but had significantly higher protein (9.9%) than either Wyalkatchem (9.4%) with Yipti intermediate (9.7%). Grain yield was greatest on the Vertosol whereas wheat growing on this soil produced the lowest protein content. Applying N fertiliser increased grain yield, crop N uptake and protein across all 3 varieties. There was no significant interaction between soil type and eCO_2 or between variety and eCO_2.

Discussion

These two experiments, conducted under both CE and field (FACE) conditions, suggest that options for using current widely grown wheat cultivars to reverse the negative impact of eCO_2 on grain protein may be limited. Although there were strong variety (and N rate) effects on grain protein in both experiments, these individual responses were not affected by CO_2 treatment.

Doubts have been raised about use of small pots (such as used in the CE experiment) to study CO_2 effects on grain protein (Taub et al 2008). In our experiment there were initially significant biomass responses to eCO2 in the CE study but this did not translate to biomass or grain yield responses at maturity (Table 2), perhaps indicating pot limitations. The difficulty of generalising CE results on grain protein to field conditions is also underlined by the change of the relative ranking of protein content of the 3 varieties common to both experiment: Wyalkatchem was highest in the CE (data not shown) yet lowest (cf. Gladius and Yipti) in SoilFACE (Table 3).

Table 2. Average effect of eCO_2 on mean shoot and root dry matter (DM) at anthesis (g/pot), maturity shoot DM (g/pot), tiller number at maturity (tillers/pot), grain yield (g/pot), kernel weight (mg) and grain number (grains/pot) of nine wheat varieties grown under three levels of soil N in the glasshouse. Values in sub-table are l.s.d. (P = 0.05) n.s. not significant (P = 0.05); * F = 0.063 **F = 0.055

Ambient CO_2			Elevated CO_2		
0 kg N/ha	40 kg N/ha	120 kg N/ha	0 kg N/ha	40 kg N/ha	120 kg N/ha
Anthesis shoot DM (g/pot)					
9.6	14.7	17.8	9.9	15.4	19.4
Anthesis root DM (g/pot)					
1.3	2.0	2.2	9.9	1.6	2.0
Maturity shoot DM (g/pot)					
12.8	24.1	36.1	13.7	23.0	36.1
Maturity tiller number (tillers/pot)					
4.1	8.9	13.2	4.7	9.2	13.9
Grain yield (g/pot)					
6.2	12.4	19.3	6.8	11.4	19.6
Grain protein (%)					
8.7	8.3	10.0	8.8	8.6	9.8
Kernel weight (mg)					
44.6	48.1	47.2	45.5	42.7	43.3
Grain number (grains/pot)					
142.2	258.3	412.2	148.4	267.2	455.1

ANOVA (lsd)

Variable	CO_2	N rate	Variety	CO_2 x N rate	CO_2 x variety	N rate x variety
Anthesis shoot DM	0.53	0.65	n.s.	n.s.	n.s.	n.s.
Anthesis root DM	0.13	0.16	0.28	0.23*	n.s.	n.s.
Maturity shoot DM	n.s.	1.28	2.21	n.s.	n.s.	n.s.
Maturity tiller number	0.42	0.51	0.88	n.s.	n.s.	1.53
Grain yield	n.s.	0.97	n.s.	n.s.	n.s.	n.s.
Grain protein	n.s.	0.39	0.68	n.s.	n.s.	n.s.
Kernel weight	2.23	n.s.	4.72	n.s.	n.s.	n.s.
Grain number	11.9	14.6	25.3	20.6	n.s.	n.s.

Grain protein is also influenced by a range of other factors including water supply and temperature (Altenbach et al 2003). In contrast to the CE experiment, where water was kept non-limiting, rainfall was well below average throughout most of the growing season in SoilFACE and supplementary irrigation had to be applied near anthesis just to prevent crop failure. Under such conditions, crops would fill grains under water stress (terminal drought) where any post anthesis N uptake is very limited (Paltra and Fillery 1993). N supply to grains will then come mainly from remobilisation. Furthermore, protein responses in SoilFACE were affected by soil type, which not only varied in initial soil nitrate supply (and potential ability to mineralise N during the growing season) but also physicochemical conditions such as salinity and sodicity in the subsoil (Table 1) which may have influenced the ability of the different wheat varieties to access soil nitrate and water, and in turn, grain yield and protein responses to eCO_2.

Table 3: Influence of soil type and N rate (0 and 75 kg N/ha) on grain yield (g/core), protein (%) and total N uptake (mg/core) of Gladius, Wyalkatchem (Wyalk) and Yipti wheat varieties under Ambient (amb) and eCO_2 in SoilFACE in 2014. (ns: not significant (P=0.05) ; * F= 0.053; ** F = 0.069)

CO2	N rate kg/ha)	Calcarosol			Vertosol			Chromosol		
		Gladius	Wyalk.	Yipti	Gladius	Wyalk.	Yipti	Gladius	Wyalk.	Yipti
Grain yield (g/core)										
amb	0	10.1	10.8	8.8	13.9	15.5	15.2	10.0	12.1	14.2
amb	75	15.8	16.9	16.6	22.8	22.7	19.6	11.6	12.6	10.5
eCO_2	0	9.9	12.3	10.8	18.3	17.1	18.9	16.0	19.8	18.2
eCO_2	75	17.4	24.4	21.3	28.5	33.2	24.8	12.1	21.7	18.3
l.s.d. (5%): CO_2 2.70 ; N 1.45 ; Soil 1.79; Var 1.76 ; CO_2 x N 0.077 ; N x Soil 2.60 ; CO_2 x Var ns ; N x Var ns ; Soil x Var ns										
Grain protein (%)										
amb	0	9.1	8.9	8.4	8.1	7.1	7.5	12.8	12.5	11.8
amb	75	10.2	9.9	10.0	10.6	9.7	9.3	11.9	13.6	14.6
eCO_2	0	8.6	7.1	8.0	7.8	6.6	6.8	10.4	10.4	11.1
eCO_2	75	9.5	7.4	7.8	8.2	7.8	8.1	11.8	11.2	12.8
l.s.d. (5%): CO_2 0.50 ; N 0.37 ; Soil 0.46 ; Var 0.45*; CO_2 x N 0.69** ; CO_2 x Soil ns; N x Soil ns ; CO_2 x Var ns; N x Var ns										

In these experiments N, which was supplied early in the growth cycle, strongly influenced dry matter production. Grain protein, on the other hand, is stimulated by N application that does not increase biomass, when applied near anthesis. Experimentation is currently in progress at the AGFACE facility to assess if management strategies that delay N supply to latter in the crop cycle such as foliar application and novel fertiliser formulations can maintain or enhance protein content in future eCO_2 environments.

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Is a reduced-tillering trait (tin) beneficial under elevated CO_2 in four FACE environments?

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Abstract
The number of heads per m^2 is an important yield component in wheat, and high yielding wheat types often produce many tillers and heads. Elevated CO_2 (eCO_2) generally promotes growth and yield of wheat, and this 'CO_2 fertilisation effect' is commonly linked to increased production of biomass and tillers, and less to other yield components. In water limited environments where crops mature under increasingly dry conditions, high biomass productivity early in the season may lead to an early depletion of soil water reserves, and inability of the crop to fill grains. A restricted tillering trait, through a 'tiller inhibition gene' ('tin'), has therefore been suggested in pre-breeding research and proven to be beneficial in such environments. In this study, we address the potential trade-offs between the response of yield to eCO_2 and the restricted tillering trait. Two near-isogenic wheat lines, the freely tillering cultivar cv. Silverstar and a Silverstar line containing the 'tin' gene (Silverstar T65 "SSR T65"; CSIRO) conferring limited tillering ability, were grown side by side in four different environments (created by two different water supply levels – rainfed and supplemented by limited irrigation – during 2011 and 2012 growing seasons) in the Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facility in Horsham, Victoria. Our results indicate that eCO_2 promoted tillering in both lines, that the responsiveness of yield and growth was not restricted by tin. The tin-line showed greater depression of leaf N under eCO_2, but this did not translate to a CO_2-related depression in grain protein.

Key words
Wheat, Free-Air Carbon dioxide Enrichment (FACE), tillering trait (tin), multi-environment experiment, dryland.

Introduction

Future climates, as predicted by IPCC (2014), will provide challenging environments for wheat growth. Rising CO_2 levels in combination with the increased occurrence of dry conditions have to be considered to ensure successful crop yield. In dryland environments, crops have to cope with increasingly limited water availability towards the end of the growing season. In terminal water deficit environments, it was suggested to limit the number of heads per area (Mitchell et al. 2012). This balances the increased growth of wheat under eCO_2 due to the 'CO_2 fertilisation effect' with the increased demand for water to sustain such an increased biomass it number of heads per area. A 'tiller inhibition gene' ('tin'), has been suggested in pre-breeding research and proven to be beneficial in such environments (Dreccer et al. 2013, Mitchell et al. 2012).

In this study, the freely tillering wheat cultivar cv. Silverstar and a line containing the 'tin' gene with limited tillering ability were grown side by side in four different environments. The environments were established at the Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facility via rainfed-only and supplemental irrigation and two growing season (2011 and 2012) which provided growing seasons) in the AGFACE facility.

We tested the following hypotheses:
(1) Elevated CO_2 will promote growth and yield of the freely tillering line more than growth and yield of the restricted tillering one.

(2) Elevated CO_2 will increase tiller numbers in all cultivars, thus potentially limiting the expression of the 'tin' trait.
(3) Leaf nitrogen concentrations will be more depressed by elevated CO_2 in the restricted tillering line due to sink limitations and corresponding down-regulation of photosynthesis (Kirschbaum 2011).

Methods

The AGFACE facility is located outside of Horsham, Victoria, Australia. Annual rain fall for the two years covered in this study was 507 mm in 2011, and 287 mm in 2012. The two near-isogenic wheat (*Triticum aestivum* L.) lines, the freely tillering "Silverstar" and a Silverstar line containing the 'tin' gene (Silverstar T65 "SSR T65"; CSIRO) conferring limited tillering ability, were grown in four rings under prevailing ambient CO_2 (aCO_2) conditions and in four FACE rings under eCO_2 conditions (sample size n = 4). Half of these rings received supplemental water (Sup), whereas the other half was rainfed only (Rain). The design and operation of the Free Air CO_2 Enrichment system is described by Mollah et al. (2009).

Results

In general, SSR T65 had 50% less tillers m^{-2} compared to Silverstar, the low-tillering trait was expressed (Fig. 1). A trend for more tillers m^{-2} under eCO_2 was not statistically significant. Consistent with literature, eCO_2 increases yield (Fig. 2). Grains per head were not affected by eCO_2. At flowering, leaf nitrogen concentrations decreased significantly under eCO_2. Elevated CO_2 lead to decreased grain protein in general. eCO, decreased %N in leaves at flowering, and more so for 'tin'.

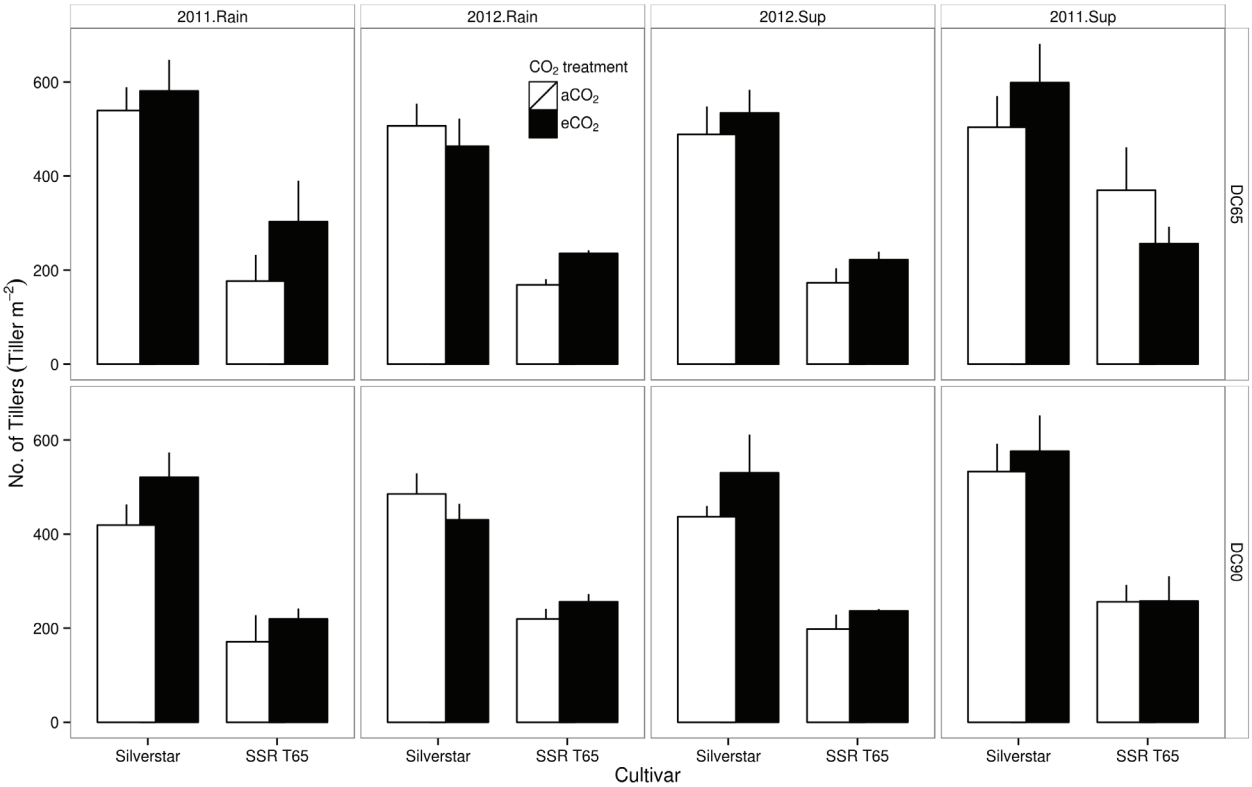

Fig. 1: Number of tillers m^{-2} in the four environments and two developmental stages (DC65, DC90) for Silverstar and the reduced-tillering 'tin' line SSR T65. The environments are ordered from left to right according to increasing yield (Fig. 2) of Silverstar in ambient CO_2. Mean and standard error.

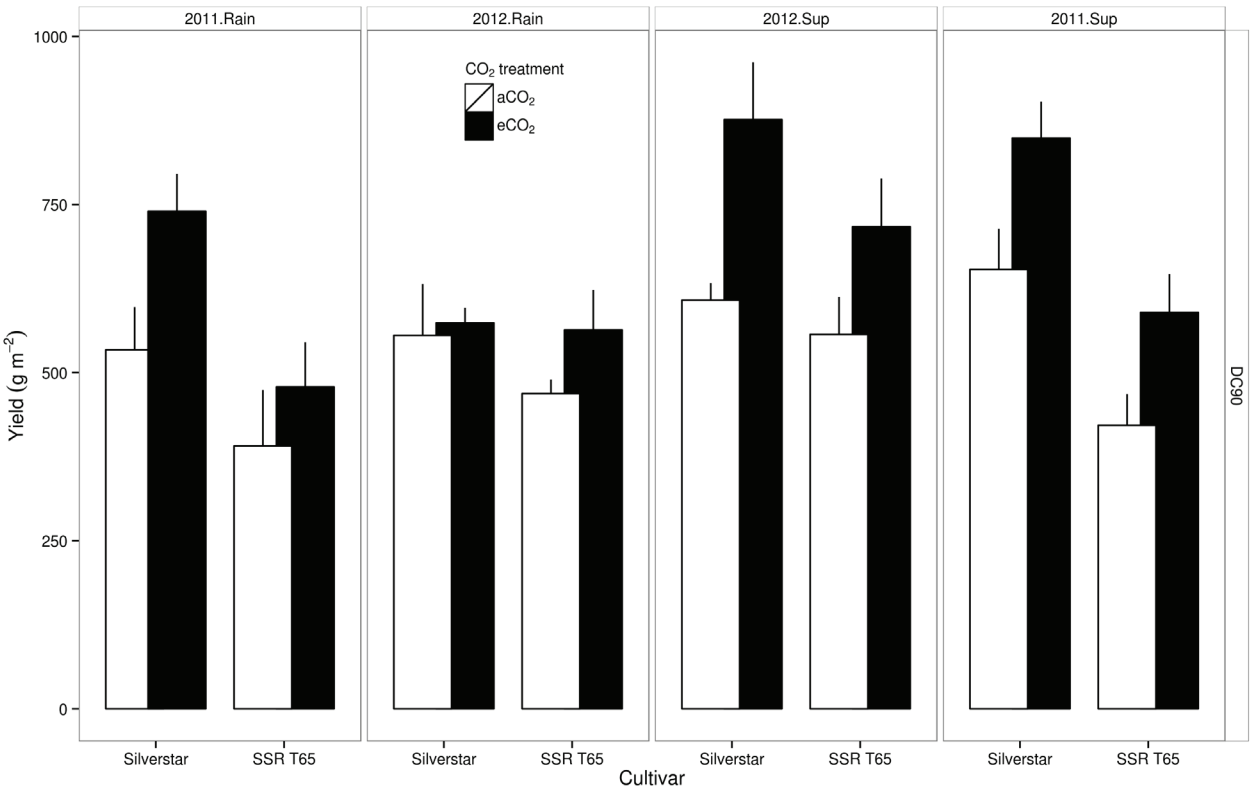

Fig. 2: Yield in the four environments for Silverstar and the 'tin' line SSR T65. See Fig. 1 for further details.

Conclusions

There was no evidence that the restricted tillering trait 'tin' limited CO_2 responsiveness of yield and growth in the tested environments. As a trend, eCO_2 promoted tillering in both lines (incl. the low tillering one), but the effect was moderate and non-significant in our data-set. The free-tillering line did not benefit more from eCO_2 compared with the 'tin' line as suggested in hypothesis 1. The relative ranking between the cultivars (high – low tillering) was maintained at both CO_2 levels. The expression of the 'tin' trait was therefore not limited due to eCO_2. Hypothesis 2 was therefore rejected.

The restricted tillering line showed greater depression of leaf N under eCO_2 (confirming hypothesis 3), but this did not translate to greater CO_2-related depression in grain protein (not shown), probably due to trade-off effects between N available in leaves for remobilisation and differences in harvest index (different amounts of leaf mass available per grain).

Acknowledgments

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Studies on barley yellow dwarf virus (BYDV) in wheat

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Abstract
BYDV has been one of the major production issues in wheat in high rainfall areas of the southern region including Tasmania, Victoria, and Western Australia. Yellow dwarf virus (YDV) are caused by a range of related luteoviruses but in wheat BYDV-PAV vectored mainly by the oat aphid (*R. padi*), has been considered the most damaging species worldwide including Australia. Sources of tolerance are thought to be available amongst existing wheat cultivars, but this has not been experimentally validated, nor has the yield advantage been quantified. In our recently GRDC funded project, we will establish one or two sites where infection can be consistent; test current varieties adapted to high rainfall wheat production zones and breeding lines supplied by breeders for BYDV resistance/tolerance; test the impact of the current source of resistance gene *Bdv2* derived from intermediate wheatgrass (*Thinopyrum intermedium*) on yield and grain quality; and provide breeders with useful BYDV tolerance or resistance in a minimum of four grower preferred varieties adapted to high rainfall zones (HRZ). This project will also screen more germplasm for alternative YDV resistance genes. Preliminary yield trials showed a significant reduction in yield due to virus infection. Screening trials in both Australia and China identified a few resistant germplasm. If new genes are found, molecular markers linked to the gene will be identified for use in breeding programs.

Key words
BYDV resistance, wheat, germplasm

Introduction
BYDV are the most widespread and damaging viruses of cereals. They infect wheat, barley, oats and grasses and are transmitted by several aphid species. The effect of the disease on yield depends on viral species or strain, time of infection and rate of spread. Yield reductions of 10% may occur even without visible symptoms of infection. Most severe losses are from early infections and can be as high as 80% (Edwards et al, 2001; McKirdy et al, 2002). The most effective approach to overcome the problem is to breed varieties with tolerance/resistance. To effectively breed varieties for BYDV tolerance/resistance, useful sources of resistance must be identified and accurate phenotyping is crucial.

The transmission of plant viruses can depend on a range of abiotic and biotic factors affecting the virus, the insect vector and the plant host. The role of these factors varies across space and time, leading to regional variation in disease incidence and impact on crops. Thus, reliable screening conditions are important to ensure accurate results. The difficulties in maintaining bioassay infrastructure, rearing aphids, and controlling virus types have meant that the CSIRO wheat breeding program is the only one to have bred and released YDV partial resistance (dual purpose winter wheats Mackellar and Manning). This is closely associated with the development of the *Bdv2* source of partial resistance. The development of testing sites in this project will assist breeders to incorporate resistance into new breeding lines.

Several YDV species reportedly infect wheat in Australia. In general, BYDV-PAV is dominant. However, mixed infections of BYDV-PAV with other YDV species are common. In oats and barley, YDVs include CYDV-RPV, BYDV-RMV, and three or more subgroup 1 YDVs (genus *Luteovirus*) related serologically to BYDV-MAV and BYDV-PAV. There are two main aphid species that colonise wheat in Australia: the oat aphid (*Rhopalosiphum padi*) and the rose-grain aphid (*Metopolophium dirhodum*) (Milne and Delves, 1999; Thackray et al., 2005). Both are reported to be efficient vectors of BYDV-PAV, but their relative importance in YDV epidemiology in wheat is uncertain.

Source of tolerance is another major issue for breeders. The only available resistance gene in wheat is Bdv2 from intermediate wheatgrass, *Thinopyrum intermedium* (Banks et al., 1995). This gene does not provide immunity and can be overcome by high inoculation pressure and early infection. Alternative tolerance or resistance genes are needed.

Recently a new project was set up to: 1) evaluate the effect of BYDV on yield and quality of wheat; 2) set up a reliable greenhouse and field based phenotyping method for the screening of YDV resistance/tolerance; 3) add the known tolerance gene to four to six grower preferred varieties; 4) screen for new tolerance genes from a large collection of wheat germplasm; and 5) map the new tolerance genes.

Materials and Methods

Development of phenotyping method

Vector efficiency for a Tasmanian isolate of BYDV-PAV was tested in an aphid culture room in Launceston. *R. padi* and *M. dirhodum*, being the two most commonly encountered species on barley in Tasmania, were reared under controlled conditions in the culture room, given access to infected barley leaves for 48 h and then transferred to healthy barley plants at the 3-leaf stage for 48 h (one aphid per plant). Plants were then sprayed with insecticide to remove the aphids and allowed to grow for 4 weeks before being tested for BYDV infection by ELISA test.

Field trials

Thirty two wheat varieties and/or breeding lines (including two barley controls and one oat control) were sown in 2014-15 growing season at Cressy Research Station in Tasmania, Manjimup Horticultural Research Station in Western Australia, and UNE, Armidale NSW, with two treatments: high BYDV (natural BYDV spread (no insecticides used)) and low BYDV (using seed dressing) for WA; high BYDV (BYDV viruliferous aphid spreading) and low BYDV (imidacloprid application on seed and 2 aphicides in-crop) for NSW; and high BYDV (natural BYDV spread with no insecticides used) and low BYDV (continuous spraying for aphids) for TAS. Spreader rows of YDV susceptible oat cv. Eurabbie sown at 100 kg/ha between each replicate block was used to assist uniform inoculum across trial sites. BYDV symptoms and plot yields were assessed.

Screening trials in China

More than 250 Chinese wheat core collections were screened for BYDV tolerance in both Yangzhou University and Chinese Academy of Science where a screening facility has been established. Among these collections, 150 were winter type and 100 were spring type. In Chinese Academy of Science, all the accessions were sown in hill plots with 4 replications. Various reared aphids (*Schizaphis graminum*, *Rhopalosiphum padi*, Sitobion avenae) carrying BYDV-PAV were used to inoculate the plants. In Yangzhou University, each collection was sown in a hill plot with two replications. BYDV virus infected aphids were inoculated to individual plants. BYDV tolerance was scored according to visual symptoms.

Screening trials in Tasmania

Over 100 germplasm lines sourced from the Cereal Collection Centre of Australia were screened in single rows in the field, and in tanks with controlled water supply at Mt Pleasant Lab, in the 2014-15 growing season. Natural BYDV spread occurred, and no insecticides were applied. BYDV tolerance was scored according to visual symptoms.

Results and Discussion

R. padi is more effective in transmitting the virus

60% of plants exposed to *R. padi* became infected with BYDV, while only 2% of plants exposed to M. dirhodum became infected. 12% and 6% of plants showed borderline results for *R. padi* and *M. dirhodum* respectively. This experiment will be replicated to confirm results and *R. maidis* will be reared and added to future trials.

BYDV caused significant yield reduction of wheat varieties

Good infections of the virus were observed in the non-sprayed plots of sensitive varieties. Figure 1 shows the average scores and yield loss due to the virus infection from the trial in Cressy Research Station of Tasmania.

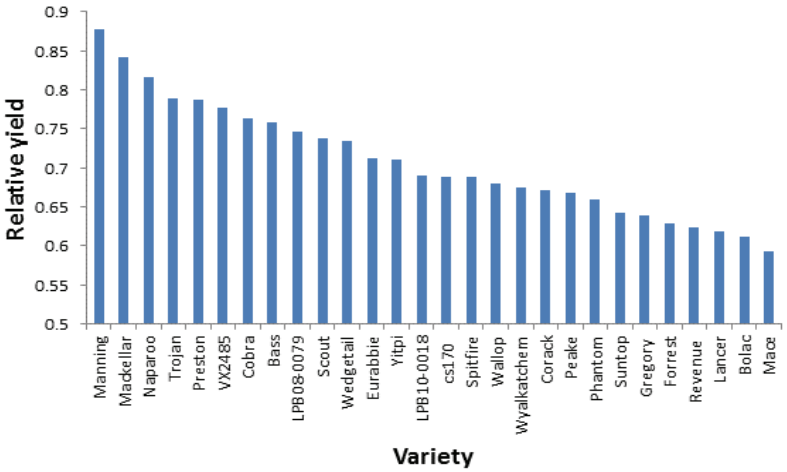

Figure 1: Relative yields of selected wheat varieties/breeding lines under BYDV disease stress. Results are from the field trial in Cressy Research Station of Tasmania.

Most of the varieties showed severe symptoms of virus infection with only Manning and Mackellar showing good resistance to BYDV. The yield data also showed a consistent result with the symptom scores. However, some varieties, i.e. Gregory and Forrest, showed less symptoms but had greater yield loss (>36%). The yield loss due to virus infection ranged from 41 to 12% with the two tolerant varieties, showing only 12% and 15%, respectively.

Conditions were unusually dry during trial growth in the NSW trial, with half average rainfall during the growing season. Consequently, aphids were virtually absent due to the lack of green vegetation and little natural infection occurred, thus the effect of BYDV on yield was not scored.

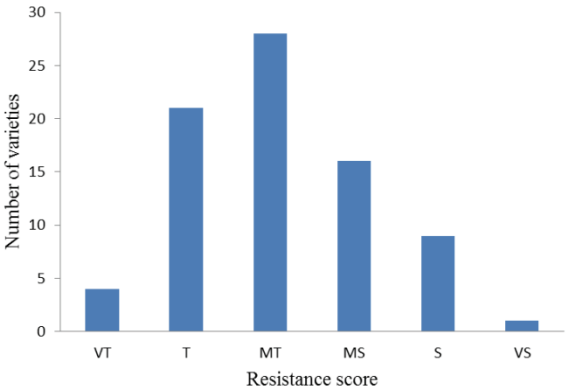

Figure 2 Distribution of BYDV resistance of 100 germplasm lines from Cereal Collection Centre of Australia, based on symptom resistance

In WA trial, virus spread was extensive throughout the entire trial with little difference in symptoms between the 'high' and 'low' virus blocks. Seed dressing only provided protection for 4-6 weeks. Of the lines tested only Mackellar rated as moderately resistant, all other lines tested ranged from very susceptible to moderately susceptible with symptoms of leaf streaking being the most predominant. From ELISA testing, BYDV-PAV was the predominant virus present, with CYDV being detected occasionally. Yields were not included in this paper since little difference was observed between the 'high' and 'low (control)' virus blocks.

YDV resistance/tolerance of germplasm from Cereal Collection Centre of Australia and China
Preliminary results from screening in single rows and in tanks showed some resistance in some lines, based on symptom tolerance (Figure 2). Further testing of bread wheat and durum wheat will be conducted this year in combination with Chinese introductions.

Based on the symptom, the first year's results showed that most of the germplasm was very susceptible to BYDV with only a few of them showing tolerance (Figure 3). One of the landrace has shown much

better tolerance than known tolerant varieties (Zhong 4, Zhong 5) which possess the tolerance gene from intermediate wheatgrass. Further mapping study will be conducted by crossing this germplasm with sensitive varieties and the variety (Mackellar) with Bdv2 from intermediate wheatgrass.

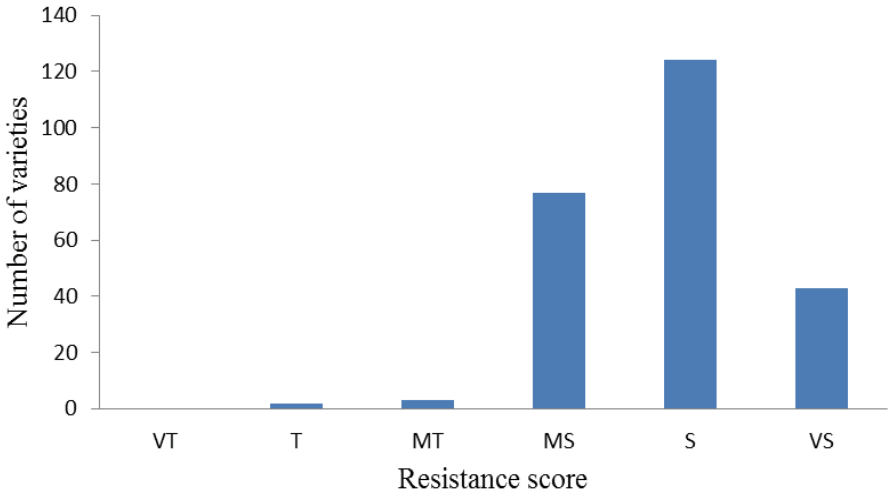

Figure 3: Distribution of BYDV resistance of 250 Chinese core collections

Conclusions

In conclusion, BYDV showed significant effect on wheat grain yield, causing up to 40% yield reduction in susceptible varieties. A new source of tolerance has been identified from Chinese wheat core collection, which can be used in breeding program.

Acknowledgement

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Grain quality of rainfed rice (*Oryza sativa*) genotypes in Central Queensland, Australia

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Abstract

Water is a major cost (20-30%) for Australian rice production as the industry water use is very high (12.3 ML/ha) due to flood irrigation. Developing appropriate rainfed rice varieties provide alternatives for the rice industry to maintain growth while the cost for water is increasing and availability is decreasing. However, maintaining high grain quality from rainfed production systems may pose challenges. Thirteen dryland rice genotypes (7 long 6 medium grain lines) were tested during the summer rainy season in Alton Downs, QLD under rainfed and strategic irrigation management in the 2013/14 season. Measured grain quality parameters only differ due to varieties but not due to water management practice (rainfed vs strategic irrigation). Four of the medium grain varieties (Lasix XB, Inaminka XD, Linklaer A1 and Laski VII) produced grain yield of 4 – 5 t/ha with strategic irrigation but were compromised with low amylose and grain protein. The gel temperature was generally higher for long grain and lower for medium grain type varieties. The millout percentage however was not linked to grain type nor to irrigation method, and all tested varieties recorded millout in excess of 50%. All tested medium grain types were earlier for maturity compared to long grain type. Therefore, the planting time for the long grain type may need to be adjusted to maintain their yield and quality. Yield and detailed grain quality analysis from crop grown in wider agro-ecological zones with full growing seasons will be presented from crops planted in the 2014/2015 season.

Key words

Rainfed rice, Dry land rice, Water use efficiency, Rice quality

Introduction

Rice (*Oryza sativa*) is a major food crop for nearly half of the world's seven billion population. 90% of rice produced in the world is consumed in Asia. However, consumption of rice is also increasing since 1960s in Africa, Europe, USA and Oceania. In Australia rice is grown in three states (New South Wales, Victoria and Queensland) producing one million tonnes and is exported to 60 countries generating AU $ 800 million revenue per annum (RIRDC 2011). Australia's climate in southern states (NSW, VIC) makes it ideal for production of high quality medium grain rice, grown predominantly as flood irrigated crop, consuming 11% of irrigated water use by rice industry. Water use by the rice industry gradually fell between 2000/01to 2008/09 by around 2000 GL due to smaller planted areas during the drought years and increasing cost for irrigation water. Producing more rice with less water is current and future challenge for all rice producers globally.

Rice grain quality is determined by measurable physical, chemical, and sensory characteristics that are genetic or acquired. Physical grain qualities include shape, translucency and whiteness of the grain; and cooking qualities include texture when hot and cold, cooking time and digestibility, while the sensory quality parameters include fragrance, aroma and taste. Grain quality is defined by the markets based on the intended end use of the rice. This paper presents the quality parameter of 13 lines of rice grown with and without supplementary irrigation during wet season of 2013/2014 season in central Queensland Australia.

Materials and methods

Rice cultivars

Seed samples of thirteen rice genotypes were obtained from Australian Agricultural Technology Ltd (AAT). The genotypes used in the experiment are Lasik VII, Sunkiss PII, Linklatter A1, Linklatter BII, Dummeriney II, Lasik IX, Inaminka MB, Lasix XB, Lasik X11, Inaminka XB, Inaminka XD, Unnamed, Duminey. Two new varieties of rice samples (polished rice) were received from China as standard check variety for grain quality analysis. There were seven long grain type and six medium grain type varieties in the trial (Table 2)

Performance of each genotype was tested under rainfed and irrigated conditions of supplementary water application when the soil moisture at 20-30 cm depth was below refill value (21 mm/100 mm). The

experiment was conducted during wet season (January-May 2014). A randomized complete block design (RCBD) with two replications for each cultivar was used in the field experiment conducted at Alton Downs, Rockhampton, QLD. The rice seeds were directly seeded at a rate of 40 kg/ha by tractor mounted seed dibbler into the soil during the wet season (January-May 2014). The field was fertilized with 100kg N/ha before planting of the crop entirely as basal application.

Whole plot harvest as performed by plot harvester, along with quadrats of 2 m2. Grains were manually threshed and dried to 12 % moisture. Random samples of 150 g were collected from each plot for grain quality assessment at the DPI NSW, Rice Chemistry Laboratory at Yanco Agriculture Institute, Industry and Investment NSW (I&I NSW). Assessment of rice physical quality parameters included: millout %, grain dimensions and chalk content and colour. Cooking qualities included: amylose content, gelatinisation temperature, viscosity and nitrogen content (as %NIR). All measurements followed the rice grain quality assessment protocol from the DPI NSW (Ward and Martin 2009).

Statistical analysis

The data obtained for the disease screening was analysed using Analysis of Variance (ANOVA). The analysis was performed using GenStat statistical package, Version 16. (VSNI Ltd, UK). A value of $p \leq 0.05$ was considered as significant.

Results and discussion

Grain yield

All long grain types were longer in duration (160-180 days) for maturity whereas all medium grain types matured earlier (150-160 days). Grain yield of the medium grain types varied from 2.19 to 3.85 t/ha for rainfed cultivation and 3.48 to 4.68 t/ha for strategic irrigation (Table 1). The three highest yielding varieties under strategic irrigation were Lasix XB (4.68), Inaminka XD (4.57 t/ha), and Linklatter A1 (4.48 t/ha), whereas under rainfed condition Sunkiss P11 produced the highest yield (3.85 t/ha). On average, strategic irrigation increased rice yield compared to rainfed system by 224%. The interaction effects due to variety and irrigation method was not significant.

Table 1: Yield and millout of rice varieties in two different irrigation management system for rainfed rice genotypes (M- medium grain and L- long grain).

Varieties	Lines	Grain type	Paddy yield (t/ha)		Millout (mean ± SD)	
			Rainfed	Strategic irrigation	Rainfed	Strategic irrigation
Lasik VII	3	M	2.12	4.20	0.51±0.03	0.43±0.01
Sunkiss PII	4	M	3.85	3.48	0.59±0.08	0.56±0.03
Linklatter A1	6	M	2.71	4.48	0.52±0.02	0.40±0.01
Linklatter B1	9	L	0.10	3.03	0.55±0.01	0.48±0.08
Dummeriney II	10	L	0.84	2.38	0.59±0.00	0.58±0.00
Lasik IX	11	L	0.49	3.08	0.59±0.02	0.60±0.00
Inaminka MB	12	L	0.26	2.81	0.63±0.01	0.59±0.01
Lasix XB	13	M	2.19	4.68	0.60±0.00	0.60±0.05
Lasik XII	15	L	0.11	1.34	0.58±0.03	0.58±0.01
Inamika XB	16	L	0.12	2.24	0.56±0.05	0.61±0.00
Inaminka XD	17	M	2.99	4.57	0.59±0.00	0.56±0.03
Unnamed	18	L	0.10	1.81	0.59±0.01	0.59±0.00
Duminey	19	M	2.71	3.64	0.58±0	0.57±0.02
Average			1.43	3.21	0.57	0.55
LSD (0.05%)	Treatment (T)		0.358***		0.174 ns	
	Variety (V)		0.912***		0.037 ***	
	T×V		1.289 ns		0.064 ns	
CV(%)	Treatment		2.5		2.4	
	Varieties		27		3.1	

Millout

Millout ranged from 51-63 % in rainfed and 40-61% under strategic irrigation (Table 1). Highest yielding varieties Lasix XB, and Naminka XD recorded higher millout, whereas Linklatter A1 had lowest millout of 40%. Hence this variety cannot be recommended for general production purpose. Chalk is an unfavourable traits for cooking rice. It is caused by poorly packed crystalline regions of starch that reflect rather than transmit light. The susceptibility to form high amounts of chalk is a genetic trait, but strongly influenced by high temperature during grain filling.

Amylose content

Cooking qualities of the rice are generally associated with the grain variety. Amylose content varied significantly due to variety only and not due to water management. Amylose content of tested lines varied from as low as 17 to as high as 24.4. Highest amylose content recorded by Lasik XII and unnamed variety whereas lowest amylose content was observed in variety Linklater B1 (Table 2).

Table 2: Amylose and gel temperature of rice varieties in two different irrigation management system

Varieties	Lines	Grain type	Amylose % (Yanco) (mean ± SD)		Gel.Temp (mean ± SD)	
			Rainfed	Strategic irrigation	Rainfed	Strategic irrigation
Lasik VII	3	M	18.87±0.25	19.16±0.64	64.91±0.23	65.29±0.48
Sunkiss PII	4	M	21.45±3.78	19.2±0.16	68.82±5.1	65.19±0.59
Linklatter A1	6	M	19.11±0.42	19.75±0.11	64.82±0.1	64.85±0.61
Linklatter B1	9	L	17.15±0.05	17.69±0.63	75.05±0.24	75.1±0.29
Dummeriney II	10	L	18.16±0.22	19.15±0.01	74.55±0.01	74.78±0.12
Lasik IX	11	L	18.16±0.01	18.82±0.33	74.46±0.13	74.72±0.20
Inaminka MB	12	L	18.45±0.02	18.53±0.14	74.48±0.30	74.71±0.04
Lasix XB	13	M	19.6±0.57	20.09±0.34	64.92±0.23	65.37±0.09
Lasik XII	15	L	24.07±0.36	24.37±0.17	71.96±0.07	71.97±0.11
Inamika XB	16	L	21.41±4.09	24.43±0.2	68.54±5.15	72.05±0.04
Inaminka XD	17	M	19.33±0.63	19.26±0.2	64.74±0.91	65.11±0.47
Unnamed	18	L	24.16±0.13	24.01±0.07	72.04±0.01	72.06±0.04
Duminey	19	M	19.39±0.45	19.32±0.53	65.18±0.11	64.94±0.7
Average			19.95	20.29	69.57	69.7
LSD (0.05%)	Treatment (T)		1.59		1.769 ns	
	Variety (V)		1.868***		2.186 ***	
	T×V		2.352		2.98 ns	
CV(%)	Treatment		0.6		0.2	
	Varieties		4.3		1.4	

Gelatinisation temperature

Gelatinisation temperature differ significantly only with variety and not by irrigation method or interaction between variety x and irrigation method. Rice has a gelatinisation temperature of 65–80°C. Gel temperature of these tested lines varies from 64-75%. The higher gel temperature has been recorded by all long grain types compared to mid grain types (Table 2).

Nitrogen and protein content

Grain physical qualities can be affected by the growth conditions of the plant, in particular high temperatures during grain filling, field fertilisation (e.g. N kg per hectare) and harvest moisture. The grain N, and protein content differed only due to varieties and not by irrigation, and the interactions of N x V (Table 3). Grain N content ranged from 1.3-1.8%. Generally N content is greater in long-grain compared to medium and also negatively correlated with yield.

Table 3 Nitrogen and protein of rice varieties in two different irrigation management system

Varieties	Lines	Grain type	N% (mean ± SD)		% protein (mean ± SD)	
			Strategic Irrigation	Rainfed	Strategic Irrigation	Rainfed
Lasik VII	3	M	1.66±0.03	1.56±0.08	9.89±0.16	9.3±0.45
Sunkiss PII	4	M	1.61±0.04	1.56±0.04	9.6±0.24	9.31±0.27
Linklatter A1	6	M	1.59±0.09	1.49±0.03	9.45±0.53	8.87±0.19
Linklatter B1	9	L	1.79±0.17	1.82±0.05	10.68±1.02	10.8±0.3
Dummeriney II	10	L	1.84±0.14	1.75±0.1	10.97±0.83	10.4±0.57
Lasik IX	11	L	1.83±0.02	1.81±0.05	10.89±0.12	10.76±0.32
Inaminka MB	12	L	1.79±0.02	1.84±0.02	10.67±0.11	10.97±0.11
Lasix XB	13	M	1.36±0.3	1.4±0.21	8.08±1.8	8.31±1.25
Lasik XII	15	L	1.67±0.03	1.61±0.04	9.94±0.16	9.59±0.21
Inamika XB	16	L	1.65±0.09	1.68±0.01	9.8±0.55	10.01±0.06
Inaminka XD	17	M	1.54±0.01	1.58±0.06	9.15±0.08	9.43±0.35
Unnamed	18	L	1.71±0.07	1.67±0.02	10.2±0.41	9.96±0.15
Duminey	19	M	1.51±0.04	1.57±0.06	8.98±0.25	9.35±0.37
Average			1.66	1.64	9.87	9.77
LSD (0.05%)	Treatment (T)		0.345 ns		2.051 ns	
	Variety (V)		0.16 ***		0.955 ***	
	T×V		0.188 ns		1.121 ns	
CV (%)	Treatment		1.6		1.6	
	Varieties		4.5		4.5	

Conclusion

Large genetic variation noted among rainfed rice genotypes for yield and quality parameters. This is leading towards the opportunity for multiplication trials particularly in wet tropics in NQLD. Recent trials have been focused on optimizing the agronomic practices for the elite lines and rigorous assessment of grain quality.

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Maize yield determination in the Northern Region: Hybrid by environment by management interactions

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Abstract
In Maize, as with most cereals, grain yield is mostly determined by the total grain number per unit area, which is highly related to the rate of crop growth during the critical period around silking. Management practices such as plant density or nitrogen fertilization can affect the growth of the crop during this period, and consequently the final grain yield. Across the Northern Region maize is grown under a large range of plant populations under high year-to-year rainfall variability. Clear guidelines on how to match hybrids and management across environments and expected seasonal condition, would allow growers to increase yields and profits while managing risks. The objective of this research was to screen the response of commercial maize hybrids differing in maturity and prolificity (i.e. multi or single cobbing) types for their efficiency in the allocation of biomass into grain.

A field experiment was carried out at Gatton Research Station, Queensland where four different hybrids were grown at a range of plant populations and levels of environmental productivity.

Results show that prolific hybrids (i.e. multi cobbing) had similar or higher yields than non-prolific hybrids as consequence of a higher number of fertile tillers per plant. The role of fertile and infertile tillers in rainfed maize cropping is discussed.

Key words
Zea mays L, tillering, water, nitrogen.

Introduction
Maize grain yield increased steadily since the introduction of hybrids, first in the USA and next in the rest of the world (Duvick, 2005). This trend can be attributed to both breeding and agronomic management practices. Yield in maize is mainly determined by grain number per unit of area (Otegui 1995; Maddonni et al., 2006 and reference quoted therein), which depends on the rate of crop growth around flowering; a variable strongly affected by management and seasonal conditions. In the northern region, farmers use management practices like plant population and nitrogen (N) fertilization to reduce crop water use early in the season i.e. transfer the use of water from the vegetative to reproductive stages. However there is evidence that, when planted at low plant populations (2-3 pl m^{-2}), commercially available hybrids tend to produce tillers. These tillers use water and nutrients and can produce no grain. The aim of this study was to quantify the allocation of biomass between productive and non-productive stems and its effects on yield for a range of recently released maize hybrids.

Materials and methods
General conditions
An experiment was carried out under field conditions at Gatton Research Station (27º 33' 08.23'' S, 152º 19' 40.78'' E; altitude 91 m), Queensland. Four hybrids with different prolificity and maturity were grown at three densities under two levels of environmental productivity obtained by supplementing irrigation and increasing levels of N supply (Table 1). The trial was sown in a split plot design, with productivity levels (N and irrigation levels) as the main blocks, and hybrid and plant density as sub-blocks. Each treatment was replicated three times. All in all, there were 72 plots (four rows per plot oriented in a north-south direction).

Diseases and insects were prevented or controlled by spraying fungicides and insecticides at the doses recommended by their manufacturers. In addition, weeds were removed by hand and controlled by spraying selective herbicides.

Table 1. Initial conditions and treatments

Sowing date	Soil Type	Initial soil water (mm)	Initial soil N (kg N ha^{-1})	Level of Productivity	Experimental treatments: Water regime[a] (mm)	Fertilization (kg N ha^{-1})	Plant density (10^3 Plants ha^{-1})	Hybrids	Prolificity type	Maturity (CRM)
22-Sep-14	Black Vertosol (Lawes)	150.5	70.8	High	Irrigated	220	30	Pac624	Low	117
							50	Pac727	High	123
							70	P1070	Medium	110
								P1467	High	114
				Low	Rainfed	100	30	Pac624	Low	117
							50	Pac727	High	123
							70	P1070	Medium	110
								P1467	High	114

[a] Periodic drip irrigations throughout the growing season, once a week up to 30 mm. Accumulated rainfall: 266 mm

Measurements and analyses

Three plants per plot were labelled and used to record phenology, and leaves and tillers emergence twice a week. At silking and +21days after silking, plants from a linear meter in each plot were harvested. The total number of plants and tillers were counted, and plants were separated into cobs, tassels, main stem and tillers, and leaves. All subsamples were oven-dried at 65 ºC during 96 h and weighed. At maturity, 3 linear meters were hand harvested, and grain yield and its main components determined. The data was subjected to analysis of variance and regression analysis to study the relationships between variables of interest.

Results

The main source of variation affecting yield was the level of productivity (Table 2). However, hybrids also differed significantly, and productivity × plant population interaction for yield, biomass and grain weight showed a magnitude similar or higher to that of the hybrid effect.

Table 2. Means and mean square values for yield, above ground biomass, harvest index, and main yield components.

		Yield (g m^{-2})	Biomass at maturity: Main shoot (g m^{-2})	Tillers (g m^{-2})	Number of grains (m^{-2})	Number of cobs (m^{-2})	Grain weight (mg grain^{-1})	Harvest index
Level of productivity								
Low		468 b	1108 b	23 b	1739 b	5.7 b	265.6 b	0.41 a
High		907 a	1809 a	227 a	2981 a	6.2 a	305.5 a	0.44 a
Hybrids (Prolificity)								
Pac624 (Low)		642 c	1480 a	91 c	2193 b	5.5 b	284.2 a	0.40 b
Pac727 (High)		649 c	1444 a	136 b	2099 b	5.8 b	294.7 a	0.40 b
P1070 (Medium)		691 b	1441 a	95 c	2529 a	5.8 b	265.4 b	0.46 a
P1465 (High)		768 a	1470 a	177 a	2621 a	6.6 a	297.9 a	0.46 a
Hybrid x Plant population (pl m^{-2})								
Pac624 (Low)	2.5	606 b	1350 c	218 c	1875 b	3.2 d	309.1 a	0.39 c
	5	730 a	1572 a	45 d	2391 b	5.5 b	278.7 a	0.44 b
	7	591 b	1517 ab	10 d	2314 b	7.8 a	264.6 a	0.36 c
Pac727 (High)	2.5	611 b	1318 c	322 b	1914 b	4.0 c	296.4 a	0.37 c
	5	677 ab	1522 a	59 d	2186 b	5.6 b	300.0 a	0.42 bc
	7	658 b	1494 b	28 d	2196 b	7.8 a	278.7 a	0.41 bc
P1070 (Medium)	2.5	573 b	1204 c	248 c	1953 b	4.1 c	278.1 a	0.40 bc
	5	731 a	1484 b	34 d	2723 a	5.5 b	259.4 a	0.50 a
	7	770 a	1633 a	3 d	2911 a	7.8 a	258.6 a	0.46 ab
P1465 (High)	2.5	744 a	1290 c	423 a	2899 a	6.0 b	307.2 a	0.44 b
	5	793 a	1572 a	88 d	2464 b	6.0 b	304.4 a	0.47 a
	7	765 a	1549 a	19 d	2499 a	7.9 a	282.3 a	0.47 a
Source of variation	**d.f.**							
Block (B)	2	12755.3^{*}	18775.5^{NS}	1237.7^{NS}	370785.0^{NS}	0.2^{NS}	2076.8^{NS}	$<0.01^{NS}$
Productivity (P)	1	3454737.0^{***}	8842965.6^{**}	750130.8^{**}	27766625.1^{***}	4.7^{*}	28670.4^{*}	0.01^{NS}
B x P	2	7063.0^{NS}	8661.7^{NS}	2055.1^{NS}	5788.1^{NS}	0.1^{NS}	833.0^{NS}	$<0.01^{NS}$
Hybrid (H)	3	59866.3^{***}	6753.1^{NS}	29458.5^{***}	1155071.3^{***}	4.2^{***}	3877.1^{**}	0.02^{***}
Plant population (Pop)	2	60489.1^{***}	509818.8^{***}	580478.0^{***}	731162.5^{**}	74.3^{***}	3572.0^{**}	0.02^{***}
P x H	3	8851.2^{NS}	11491.3^{NS}	22807.3^{***}	319908.6^{NS}	1.4^{*}	1862.2^{*}	0.01^{***}
P x Pop	2	124727.0^{***}	505163.4^{***}	412484.0^{***}	150721.8^{NS}	2.3^{**}	6819.2^{***}	0.04^{***}
H x Pop	6	16774.5^{**}	$24992.0^{NS(a)}$	12456.2^{**}	595828.6^{**}	2.2^{***}	538.0^{NS}	$<0.01^{*}$
P x H x Pop	6	3837.3^{NS}	11503.6^{NS}	10740.0^{**}	204545.9^{NS}	0.5^{NS}	691.5^{NS}	$<0.01^{NS}$
Error	44	3764.6	11249.2	3060.5	130262.9	0.4	603.7	0.02

The asterisks stand for the level of significance of the mean squares: * P<0.05; **P<0.01; ***P<0.001; NS not statistically significant

[(a)]Level of significance of the mean square HxPop interaction P=0.0586

The different hybrids and treatments resulted in a wide range of yields that ranged from 320 to 1050 g m^{-2} (oven dry). The largest effect was the level of productivity (Table 2). The yield of the different hybrids differed significantly as well. Different hybrids had different responses to plant population and levels of

productivity (Table 2). The pattern of generation and survival of number of tiller per plant is presented in Fig. 1. Tiller dynamics was analysed in terms of the maximum number of tillers formed, the rate of tiller degeneration, and the proportion of tiller surviving that were fertile. All hybrids produced tillers though prolific hybrids like P1465 had larger number surviving and fertile tillers, particularly at the lowest plant density. The main difference in the number of fertile tillers was related to tillers death (Fig. 1). Tiller senescence and death took place at the time when the competition for resources by the forming primary or secondary cob was maximum, i.e. during the cobs elongation phase.

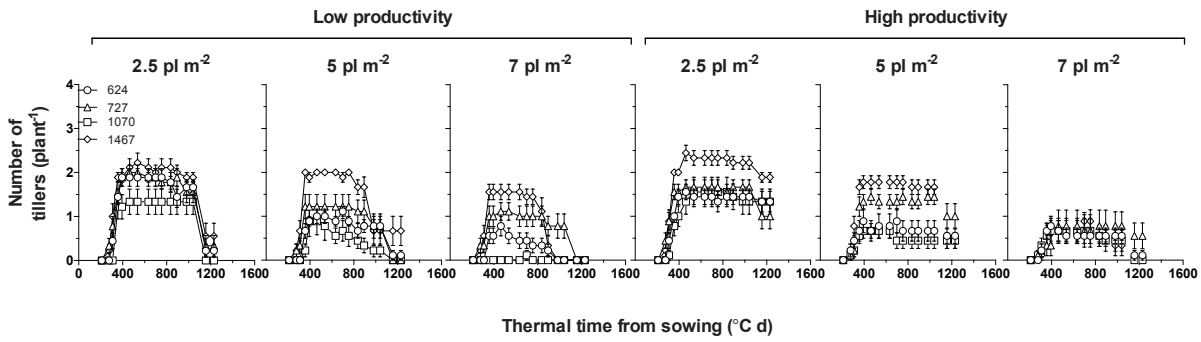

Figure 1. Dynamics of tillering as a function of thermal time from sowing, for maize hybrids growing under three plant populations: 2.5, 5 and 7 plants m^{-2}; and two levels of environmental productivity. Circles represent Pac624, triangles are used for Pac727, squares for P1070, and rhombuses for P1465. Bars correspond to *SEM.*

Significant differences in biomass between plant densities were observed only in the high productivity treatments (Fig. 2, left panel). Under low productivity all plant densities produced similar levels of biomass (Fig. 2, right panel). However, harvest index (i.e. the ratio between grain yield and biomass) was different in both environments (Table 2 and Fig. 2). Prolific hybrids had usually a higher harvest index (0.52 and 0.23 for the main shoot and tillers, respectively). The largest production of fertile tiller biomass (800 g m^{-2}) was observed in a prolific hybrid grown under high productivity and low plant density. Under the same conditions the lowest prolific hybrid, had half of that biomass (400 g m^{-2}) on infertile tillers (Fig. 2 inset left panel). Under low productivity conditions, there were no significant differences in total biomass for the main shoot or even for tillers (Fig. 2 main right panel and inset).

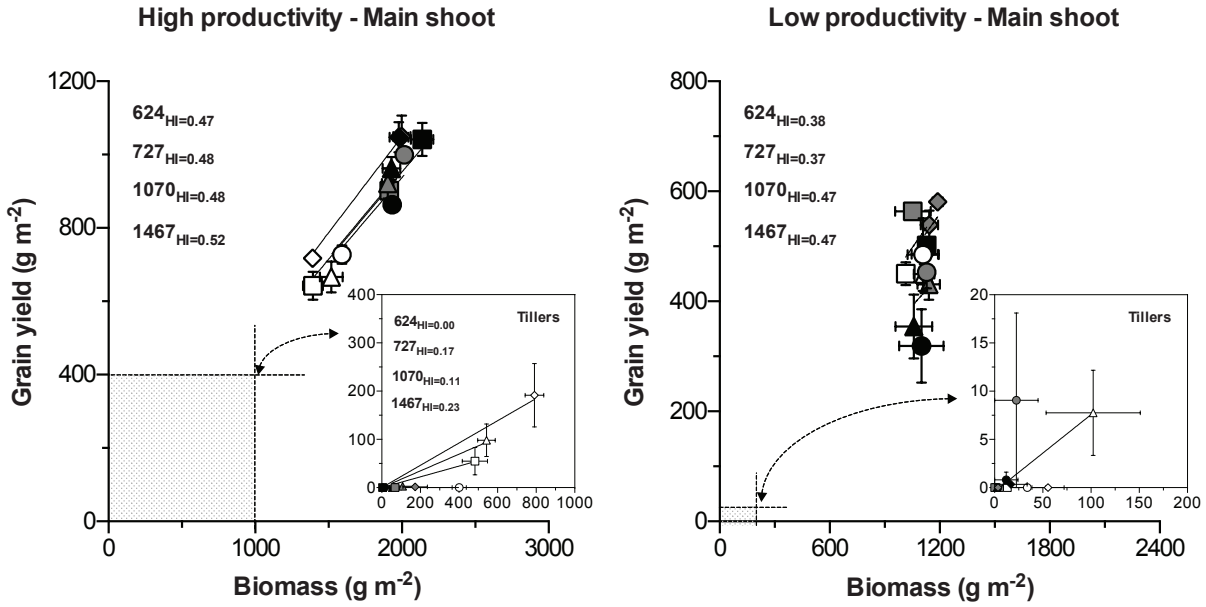

Figure 2. Relationship between yield and total biomass at maturity in the main stem and tillers (insets) for maize hybrids grown at different plant populations, under high (left panel) and low (right panel) levels of environmental productivity. Symbols correspond to hybrids: Pac624 (circles), Pac727 (triangles), P1070 (squares) and P1465 (rhombus) under low (open), middle (grey) and high (black) plant population. Insets graph correspond to tiller. Bars correspond to *SEM.*

Discussion

These results as well as those from Moulia et al. (1999) show that the most significant result is that, in a favourable environment and in the absence of neighbouring plants (low density), modern hybrids produce a large number of mostly unproductive tillering, including what is usually called basal tillering and cobs shoot prolificacy.

Here we propose that if tillering in maize would be restricted and some of that biomass e.g. up to 800 g m^{-2} under low populations and high productivity environments would be allocated to the main stem, maize yields could be significantly increased (up to 400 g m^{-2} assuming a harvest index of 0.5) (Fig. 2). Whether this is possible merit further research.

In conclusion, in this study, showed clear differences on the response of different hybrids to contrasting plant populations that show a likely pathway towards increasing the productivity of rainfed maize cropping.

Acknowledgements

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Interaction of Genotype, Environment and Herbicides in wheat (*Triticum aestivuum* L.) and barley (*Hordeum vulgare* L.) across a range of environments in Australia

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Abstract
Wheat and barley cultivars can display differential tolerance to herbicides used in Australian cereal production. Seasonal variability can be seen across single cultivars in response to herbicide application. However, it is unknown how much herbicide damage can be explained by seasonal variability, and whether cultivars respond similarly across a range of environments. Currently five Australian states are conducting herbicide by cultivar tolerance research projects; however crossover between these projects has been limited due to differing nature of cultivar and herbicide uses in each state. To overcome this, from 2010 to 2012, a series of genotype x environment x herbicide trials were simultaneously conducted across five states (NSW, QLD, SA, WA and Vic). Trials comprised of barley cultivars Hindmarsh and Buloke and wheat cultivar Janz with eight herbicide treatments and an untreated control to ensure uniformity across all states. Observations made throughout the year included normalized difference vegetative index (NDVI), grain yield, grain protein, small grain screenings and test weight. Results identified that environmental effects can significantly impact the herbicide response of barley and wheat cultivars with considerable amounts of variation observed site-to-site and year-to-year. Grouping of barley cultivars Hindmarsh and Buloke showed similar trends in results, suggesting that herbicide responses can be repeated from one season to the next. The limited correlation between the sites highlighted the degree of variation in herbicide response across environment and genotype, and therefore agro-ecological region specific testing over longer periods would be advantageous to gain increased confidence in identifying levels of herbicide tolerance.

Key words
Genotype, cultivar, herbicides, seasonal variability, cultivar response

Introduction
Wheat and barley cultivars can display differential tolerance to herbicides used in Australian crop production (Belfry and Sikkema, 2015). Similarly a single cultivar over seasons and locations can show seasonal variability in its response to herbicide application (Kong *et al*. 2009). However, it is largely unknown how much herbicide damage can be explained by seasonal conditions, and whether cultivars respond similarly across a range of environments. Despite the existence of five state based herbicide tolerance research programs across Australia, crossover between these programs has been limited due to differing cultivar and herbicide uses in each region. To overcome this, in 2010, a series of genotype x environment x herbicide trials were simultaneously conducted across each of the five states (NSW, QLD, SA, WA and Vic).Sites where responses to herbicides were highly correlated may indicate the need for fewer sites nationally to assess herbicide tolerance. However, data must be collected over subsequent seasons to support this. These data may be used to identify the optimal number of sites and seasons to determine the genetic component of herbicide tolerance and environmental conditions conducive to crop damage. These data may also aid in identifying crucially differing ecotypes to produce tolerance information spanning a broader range of environments than current national programs.

Method
A series of field experiments were conducted across the major Australian wheat-belt regions during 2010-2012 to assess the stability of herbicide tolerance of various wheat and barley cultivars. During this period 20 field experiments were conducted in South Australia, Western Australian, Victoria, Queensland and New South Wales. These experiments examined the effect of 8 different herbicides treatments on three crop

cultivars Buloke (barley), Hindmarsh (barley) and Janz (wheat). The herbicide treatments consisted 2, 4-D amine, tralkoxydim (Achieve®), metsulfuron-methyl (Ally®) and chlorsulfuron (Glean®) and an untreated control. Each of these herbicides was applied at two rates including a recommended label rate and twice the recommended label rate (Table 1).

Table 1. Herbicide treatments applied in all field experiments from 2010-2012.

Herbicide	Crop growth stage at application	Label recommended rate (a.i./ha)	Twice recommended rate (a.i./ha)
2, 4-D amine	Zadoks 15	812.5 g	1625 g
Chlorsulfuron	Zadoks 13	15 g	30 g
Metsulfuron-methyl	Zadoks 13	4.2 g	8.4 g
Tralkoxydim	Zadoks 13	380 g	760 g

Each field experiment was conducted under weed free conditions, using a strip split-plot design, with herbicides applied to strips and cultivars applied to main plots with three replications. The cultivar main plots were latinised so as not to occur more than once in the same bay. The field experiments were sown using a knife point and press wheel seeding systems. Sowing dates of experiments were different in each region depending on the season break. Seeding usually occurred within 3-4 weeks following opening rains to enable sufficient weed germination for a good 'knock-down' to be applied before seeding. This usually resulted in experiments being sown in late May to early June. An exception to this was in Wagga Wagga, NSW, where in two years an early and late time of sowing separated by approximately one month were evaluated. Herbicide treatments were applied using a small experimental plot spraying equipment fitted with air induction nozzles to deliver 80-100 L/ha water volume. Timing of herbicide treatments were based on those recommended by product labels (Table 1). After four weeks following each herbicide application, NDVI readings were recorded using a hand-held Greenseeker®. Plots were then harvested with small experimental plot machinery at maturity to determine grain yields. Grain samples were also used to measure quality parameters such as, 1000 grain weight, grain protein, small grain screenings and test weight. Statistical analysis was performed using an ANOVA in GenStat (version 16) and if the trial design deviated from a regular strip-plot the REML procedure was used.

Results

Significant interactions were observed between environment and herbicide (Table 2) with limited crossover between each region of the herbicide tolerance program. In terms of herbicide by cultivar interactions to identify experiment locations that either responded similar or distinctly different to one another, data was analysed and examined by the effects on each cultivar. The analysis of variance summary for experiment (trial) by variety by herbicide is shown in Table 2. Barley cultivars, Buloke and Hindmarsh showed a significant interaction between experiment and herbicide treatments unlike the wheat cultivar Janz which showed no significant interaction, but did show a significant interaction between the main effect of herbicides (at(Variety, Janz:HerbTrt). As the cultivar Janz had no effect of experiment location in Table 2, it would suggest that Janz responded in the same way to all herbicide treatments in all the experiments across sites and seasons.

Table 2. Analysis of variance summary across all field experiments (MET). (* indicates P<0.001 and * indicates P<0.05)**

	Df	Sum of Sq	Wald statistic	Pr(Chisq)	Sig
(Intercept)	1	49521	49521	< 2.2e-16	***
Trial	19	3650	3650	< 2.2e-16	***
Variety	2	359	359	< 2.2e-16	***
at(Variety, Buloke):HerbTrt	8	18	18	0.0239082	*
at(Variety, Hindmarsh):HerbTrt	8	32	32	0.0001121	***
at(Variety, Janz):HerbTrt	8	52	52	1.64E-08	***
Trial:Variety	38	2355	2355	< 2.2e-16	***
Trial:at(Variety, Buloke):HerbTrt	152	241	241	5.78E-06	***
Trial:at(Variety, Hindmarsh):HerbTrt	152	222	222	0.0001727	***
Trial:at(Variety, Janz):HerbTrt	152	174	174	0.1070871	NS

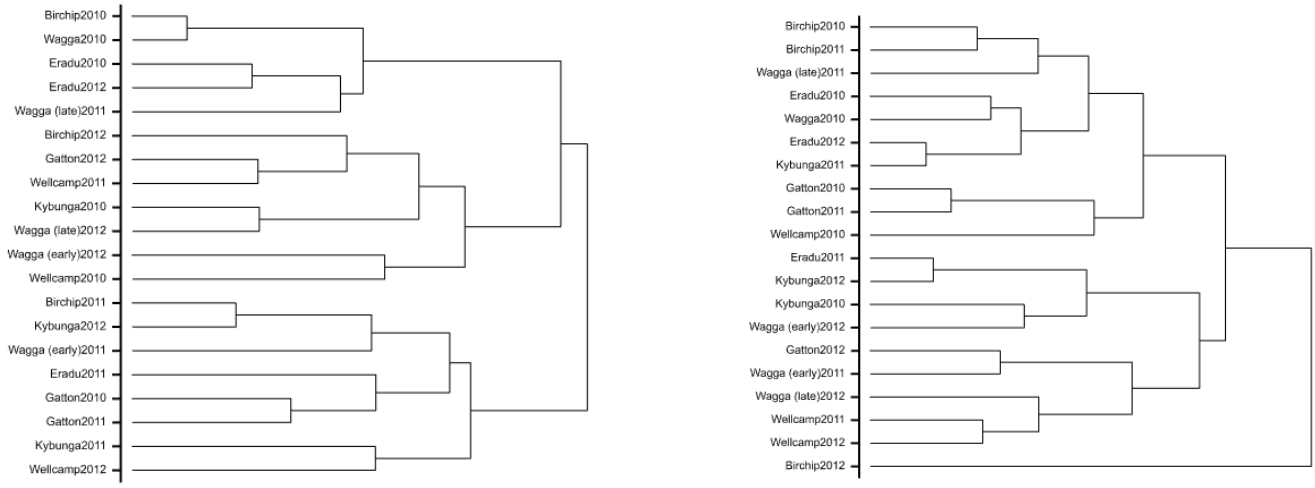

Figure 1. Denogram of the cultivar Buloke (left) and Hindmarsh (right) for each field experiment based on normalized gain yields.

The analysis of variance showed a significant interaction between experiment and herbicide treatments for the cultivar suggesting that Buloke responded differently to herbicide treatments depending on the experimental site or season. Individual experiments could be group together based on herbicide treatment response similarities (Figure 1). From the dendrogram (Figure 1) there were three main groups of experiments that were found to respond similar. These groups are as follows; Group 1, Birchip 2010, Wagga 2010, Eradu 2010, Eradu 2012 and Wagga (late) 2011. Group 2; Birchip 2012, Gatton 2012, Wellcamp 2011, Kybunga 2010, Wagga (late) 2012, Wagga (early) 2012 and Wellcamp 2010. Group 3; Birchip 2011, Kybunga 2012, Wagga (early) 2011, Eradu 2011, Gatton 2010, Gatton 2011, Kybunga 2011 and Wellcamp 2012.

The other barley cultivar Hindmarsh also was found to have a significant interaction with experiments, but the groupings of similar responding experiments was much different to those identified for Buloke. From the dendrogram showing the relationship between field experiments (Figure 1), it initially identified 3 groups with Birchip 2012 in a group of its own. The first major group consisted of 10 experiments and was still found to have a significant interaction, so it was further divided into 3 groups. This divided experiments up into five groups to show which experiments were most closely related. The groups are as follows; Group 1, Birchip 2010, Birchip 2011 and Wagga (late) 2011. Group 2; Eradu 2010, Wagga 2010, Eradu 2012, Kybunga 2011. Group 3; Gatton 2010, Gatton 2011, Wellcamp 2010. Group 4; Eradu 2011, Kybunga 2012, Kybunga 2010, Wagga (early) 2012, Gatton 2012, Wagga (early) 2011, Wagga (late) 2012, Wellcamp 2011 and Wellcamp 2012. Group 5; Birchip 2012. These groupings are different to those identified for Buloke, but show some similarities between experiments. Looking at specific sites for example Eradu 2010 and 2012 experiments are in the same group for both Buloke and Hindmarsh. Similarly Gatton 2010 and 2011 experiments and Kybunga 2010 and 2012 experiments are also consistently grouped.

Conclusion

Findings from analysis across environments would suggest there is a considerable amount of variation from site-to-site and year-to-year. Excluding findings from the cultivar, Janz, groupings of field experiments of each of the barley cultivars showed similar trends in results. This provides confidence that herbicide responses can be repeated from one season to the next, as many sites had at least 2 of the 3 years of experiments in the same grouping. This also highlights that the herbicide responses are influenced by seasonal effects; therefore three years of testing for herbicide effects should be regarded as a minimum time frame to identify the level of herbicide tolerance in each environment (Rolston *et al*. 2003). Apart from the wheat cultivar included in this study there was found to be an effect of environment (experiment location) on the herbicide response shown by the groupings of trials. These groups were not consistent for both barley cultivars. Therefore environmental effects can significantly impact the herbicide response to different genotypes (Kong *et al*. 2009).

As a result of this, it would suggest there is limited crossover between the five state based herbicide tolerance programs across Australia. The adaption of cereal genotypes is often very region specific and this appears to have an influence on the herbicide response in combination with the different soil types and weather conditions at each location (soil and weather data from each location was not available for this report). As there is limited correlation between the current sites, there is no evidence from this study to reduce the number of sites it the national herbicide tolerance program. Findings highlighted the degree of variation in herbicide response and would be beneficial to test herbicide and genotype combinations over longer time frames to gain increased confidence in identifying the level of herbicide tolerance at different sites (Rolston *et al*. 2003).

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Influence of winter-grazed dual-purpose wheat and canola crops on the forage availability in a pasture-based system

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Abstract
Benefits and risks of integrating dual-purpose crops (DPC, wheat and canola) into a pasture system are the subject of a 4-year grazing study on the NSW Tablelands. The study involves 3 treatments: pasture only (Control) and pasture with DPC grazed by either Merino ewes (ECG) or weaners (WCG). There are 3 replicates per treatment and each involves 1 flock of 6 ewes and 1 flock of 6 weaners, grazed separately and rotationally on six plots (0.23 ha each). Wheat and canola crops are grazed in winter, and managed to achieve no penalty in grain yield. We report treatment effects on the plant biomasses at the time of plot entry by the grazing flocks during the dry 2013 and the more favourable 2014 seasons, as well as the start of 2015. In 2013, for much of the growing season, the Control treatment had lower ($P<0.05$) forage biomasses than ECG and WCG, with clear pasture spelling effects on the cropping treatments. As consequence, Control animals required larger supplementary feeding than ECG and WCG animals. In 2014, plant biomasses were higher than in 2013. In 2014 and the start of the 2015, however, the plant biomasses on ECG and WCG plots were or tended to be lower than those grazed by Control animals, except when canola and wheat stubble were being grazed. Inclusion of DPC in the system effectively reduced the winter feed gap when the growing season was poor, while in a good season benefits arose from grain production and agisted grazing.

Key words
Dual-purpose crops, forage, grazing, sheep, winter, pasture

Introduction

Crop-livestock integration by using dual-purpose crops (DPC) is now practised throughout southern Australia's cropping zone and provides risk management benefits, diversifies crop rotations, reduces pressure on other feed resources (pastures) and can significantly increase both livestock and crop productivity from farms with little increase in inputs (Bell et al., 2014; Dove and Kirkegaard, 2014; Dove et al., 2015). Compared to pastures, DPC have superior winter growth (Virgona et al., 2006; Kirkegaard et al., 2008), and by providing high-quality feed for livestock during winter, DPC are valuable for filling feed gaps that occur at this time of year (Moore et al., 2009). Cropping of DP canola not only provides high-quality forage during winter, but it provides an excellent break-crop for weed and disease control in cereal-canola rotation systems (Kirkegaard et al., 2008; Bushong et al. 2012). The grazing of DPC also provides substantial benefits for pasture productivity by spelling pasture from grazing over winter (Dove et al., 2015). What is not clear, however, is how risky introducing DPC into grazing systems will be in the longer term.

A 4-year study (2013–2016) is being conducted at the NSW tablelands (Canberra) to explore how the integration of DP wheat and canola crops within a permanent pasture feedbase can be used to fill the feed gap in winter and achieve significantly more meat production from Merino sheep with manageable or lower business risk. Here, we report treatment effects on the forage biomasses at the time of plot entry by the grazing flocks during the first two grazing seasons (2013 and 2014) and the start of the third season (2015).

Methods

The experiment is being conducted at the CSIRO Ginninderra Experiment Station near Hall, ACT (35° 12' S, 149° 4' E, 600 m elevation, average annual rainfall 665 mm). Terrain is relatively flat and soil type is a Yellow Chromosol. The site is typical of large areas of moderate-fertility soils in the medium-high rainfall zone in south-eastern Australia (NSW Tablelands). Three treatments are involved: pasture only (Control), pasture with DPC grazed by ewes (ewe crop grazing, ECG) and pasture with DPC grazed by weaners (weaner crop grazing, WCG). Each treatment has three replicates (experimental units), each involving 1 flock of 6 breeding ewes and 1 flock of 6 weaners that are grazed separately and rotationally on six plots (0.23

ha each). Thus, the study involves 54 grazing plots, 9 flocks of ewes and 9 flocks of weaners. Experimental setup (*e.g.*, crops sowing) commenced in February 2012 and measurements started in November 2012. Grazing year runs from shearing to shearing (first week of November to last week of October). In the 2013 season, the Control experimental units included only 4 plots of permanent pasture (equivalent to a stocking rate of 19 DSE/ha), resulting in large supplementary feeding of animals. Consequently, in November 2013, two new plots of permanent pasture were added to the Control experimental units, bringing down the stocking rate to 13 DSE/ha starting in the 2014 grazing season.

Cropping within each replication of the WCG and ECG treatments is contained within 4 plots (out of 6), which rotate from year to year following the sequence: pasture → canola → wheat → pasture. Hence, in any grazing season, each replication in the WCG and ECG treatments include 1 plot of each of canola, wheat, 1st year pasture and 2nd year pasture, and 2 plots of permanent pastures. Grazing of wheat and canola does not follow a pre-established sequence, but the timing of grazing is decided on the basis of forage availability within the window of utilisation (winter, limited by pesticide withholding period) and to maintain grain yields. First grazing of 1st year pastures takes place 8 months after sowing and is conducted preferably with weaners. Grazing rotations on pastures are conducted on the basis of forage availability and the nutritional requirements of the animals. Wheat stubbles are grazed by ewes (ECG and WCG) soon after grain harvest (December).

Forage biomasses on grazing plots were measured immediately before or on the day of plot entry by the grazing flocks. Forage within six 0.245 m2 (0.35m × 0.7m) and six 0.469 m2 (0.375m × 1.25m) randomly placed quadrats per plot on pasture and crop plots, respectively was cut to ground level. On crops, the length of cutting (1.25 m) aimed to cover 5 rows. Three wire-mesh enclosures (1.5m × 1.5 m) were placed on each crop plot to determine grazing effect on DPC yields. The 0.469 m2 quadrat was used for measurements of plant biomasses within the enclosures as well as for determining stubble biomass after crop harvest. Cut forages were weighed fresh and sub-samples oven-dried (65 oC, 72 h) for determination of dry matter (DM) contents. At crop harvest, samples (placed in large paper bags) were dried in a naturally ventilated barn. At irregular intervals, pasture biomass samples were manually separated for botanical composition analysis: green forage (grass and clover species), senescent material (grass and clover forage species), and weeds.

Effects of treatments on forage availability were evaluated at each sampling date using one-way ANOVA.

Results

Rainfall in 2014 (674 mm) was higher and better distributed than in 2013 (584 mm); in particular, autumn in 2013 was drier than in 2014. Rainfall during the second half of February in both 2013 and 2014 allowed early sowing of DPC and pastures. Sowing of DPC in 2015 was even earlier (the first week of February), but crop establishment was initially patchy due to lack of rainfall, with signs of recovery to the start of April.

Plant biomasses at the times of plot entry by grazing animals differed among treatments only at certain measurement dates (Figure 1). In 2013, ECG and WCG ewes and weaners (born in 2012) had access to significantly higher biomasses during DPC grazing. Further, during spring 2013, pasture biomasses on plots grazed by ECG and WCG ewes were higher than on Control, an effect attributable to pasture spelling due to deferred grazing. It should be noted that in 2013 the Control treatment involved only 4 plots. In 2014 and the start of the 2015, pasture biomasses on plots grazed by ECG and WCG ewes and weaners were or tended to be lower than those grazed by Control animals (Figure 1).

The total grazing days for ewes (days/flock) in Years 1, 2 and part of Year 3 were 341, 361 and 133, respectively, whilst the corresponding grazing days for weaners were 257, 278 and 133 days, respectively (Figure 2). In 2013, ECG ewes spent 14 and 30% of their total grazing time on DP canola and wheat (including stubbles), respectively. In the same year, WCG ewes spent 30% of their total grazing days on wheat (including stubbles). In 2014, DP canola and wheat (including stubbles) provided 13 and 21% of total grazing days to ECG ewes. In the same year, WCG ewes spent 9% of their total grazing days on wheat stubbles. Both in 2013 and 2014, DP canola provided 14% of the total grazing days to ECG weaners. In 2014, neither the WCG ewes nor weaners required access to wheat crop; the wheat crop in the WCG treatment was instead grazed by agisted wethers for 21 days (26 animals/plot), with each wether gaining an average of 2.3 kg during the period. Grain yields in 2013 were lower than in 2014 (canola 1.3 vs. 3.9 t/ha, wheat 3.4 vs. 4.1 t/ha), with no significant effect of grazing on grain yield (P>0.05). Grain yields of canola and wheat did not differ between ECG and WCG treatments in either year.

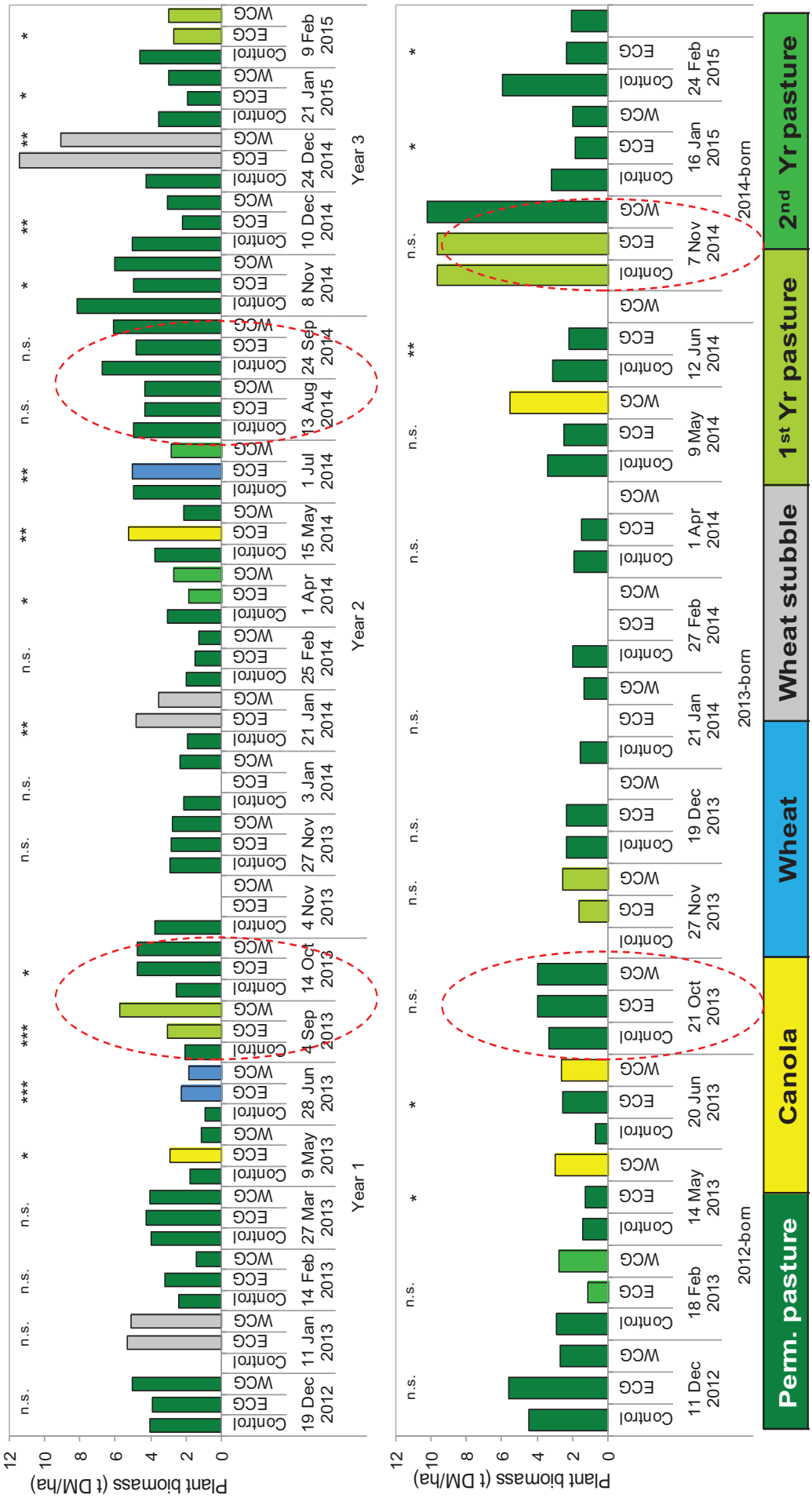

Figure 1. Mean plant biomass at entry of ewe (top) and weaner (bottom) flocks to grazing plots. Statistical significance of treatment effects at each measurement are: n.s., not significant (P>0.05); *, P<0.05; **, P<0.01. Measurements labelled by red-border ellipse correspond to times on which spelled pasture should have been found on ECG and WCG treatments. The Year 3 grazing season, which includes the new group of ewes and the 2014-born weaners, is in progress.

Plant biomass at the end of the grazing season can be a poor indicator of forage availability over summer and autumn. In 2014, pasture biomass accumulated rapidly and by mid-December 2014 about 80% of biomass was senescent material (mostly grasses); afterwards pastures on ECG and WCG treatments deteriorated rapidly both in quantity (Figure 1) and quality. On 20 February 2015, pastures on ECG and WCG treatments had significantly ($P<0.05$) lower (10 vs. 45%) and higher (40 vs. 2%) presence (dry matter basis) of green desirable forage and weed (e.g, *Chenopodium* sp.) species, respectively compared to Control pastures.

The second year pastures were cut for hay in both years. In 2014, plots on ECG and WCG treatments cut for hay had plant biomasses of 8.8 and 7.5 t DM/ha, respectively, approximately twice that in 2013. In 2013, due to feed shortages, the sheep required supplementary feeding (wheat grain) from January to September, with Control animals needing more than ECG and WCG animals (90, 29, 54 kg/ewe and 48, 45 and 7 kg/weaner, respectively). Grain feeding in 2014 was minor (12-15% of that fed in 2013) and occurred only in summer. In 2015, grain was fed to ECG and WCG sheep between 5 March and 30 April.

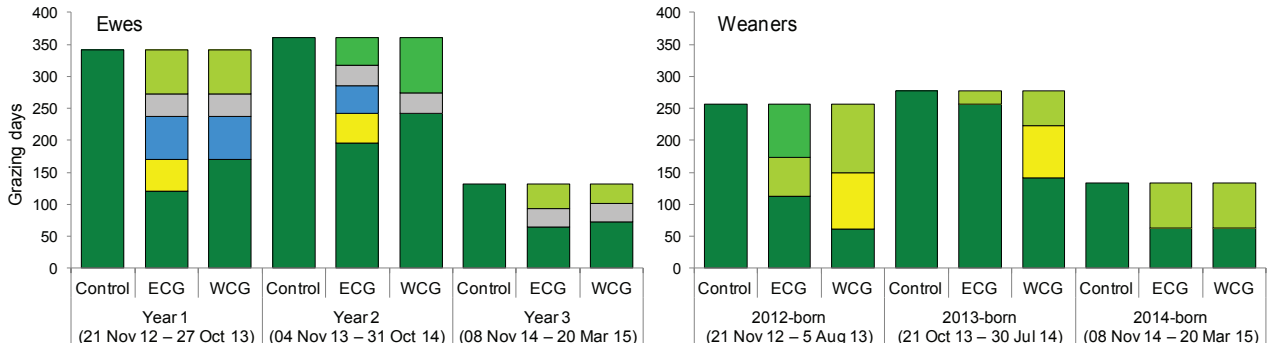

Figure 2. Mean grazing days (days/flock) for ewes and weaners distributed across the forage sources (see Figure 1 for legend description). Year 3 grazing season (including of 2014-born weaners) is in progress.

Conclusion

Including DPC in a grazing system significantly reduced the impacts of a poor autumn in 2013, with effective spelled biomass on permanent pastures. In 2014, a year with high pasture production, effects of inclusion of DPC on pasture spelling were not evident. In a favourable growing season (2014), benefits of DPC arose from agisted grazing and the high yield of grain, especially from early-sown canola. A key question to be answered in the final two years of the experiment is whether the permanent pastures in the highly intensive ECG and WCG treatments can retain enough desirable species to maintain productivity.

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Joining Ewe Lambs on Dual Purpose Canola in Southern Australia

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Abstract

Collaborative research between Victorian State Government, Meat and Livestock Australia and the CSIRO was conducted at Hamilton, Victoria, to compare the reproductive performance of ewe lambs grazed on seven forage treatments during joining in autumn 2014. The forage treatments were: 1). canola (cv. Hyola 971CL), 2). canola (cv. Taurus), 3). forage brassica (cv. Winfred), 4). lucerne (cv. StaminaGT6), 5). chicory (cv. Puna II), 6). plantain (cv. Tonic) and 7). perennial ryegrass+pellet supplement (cv. Banquet II) (control). The canola was subsequently harvested in November 2014. Ewe lambs grazing canola or forage brassica had higher daily liveweight gains during joining than ewe lambs on the perennial ryegrass+pellet treatment (147 g/d from Hyola 971CL, 132 g/d from Taurus, 137 g/d from Winfred and 2 g/d from perennial ryegrass (LSD=67.62, P<0.001). Of the 288 ewe lambs joined, 30 failed to conceive (~10%). Reproductive rate (number of foetuses scanned per ewe joined) was 1.46 from Hyola 971CL canola, 1.59 from Taurus canola, 1.28 from Winfred forage brassica and 1.03 from perennial ryegrass (LSD=0.35, P=0.059). Grazing the canola in autumn resulted in no canola yield penalty relative to the ungrazed control, with canola seed yields of between 2.46 and 2.24 t/ha achieved from grazed and ungrazed canola plots (LSD=0.62, P>0.05). Further grazing of the canola during winter and then cutting the canola for silage in late August did however result in significant canola yield penalty (P<0.001), with canola yields in the silage plots reduced by approximately 60% relative to the ungrazed control.

Key words

Canola, ewe lambs, reproduction, high rainfall, autumn feed

Introduction

Sowing winter type canola in spring in southern Australia's high rainfall zone offers an opportunity to graze the forage during summer and autumn, before harvesting the canola as a seed/oil crop in its second spring. Grazing canola in summer and autumn provides feed of high nutritive value at a time when feed supply from pastures is often low and of poor quality. The reproductive performance of ewe lambs is a key driver of profitability in south west Victorian prime lamb systems (Young et al., 2010). Having ewe lambs on a rising plane of nutrition leading up to joining, such that the ewe lambs reach a critical liveweight of 40 kg at joining, increases the likelihood of successful conception and the rate of twinning (Coop, 1962). Green brassica crops could also have a flushing effect on ewes, as occurs on green lucerne and chicory (King et al., 2010). However, spring sown canola may have a number of risks. High levels of nutrition during joining can reduce ewe conception rates (Parr et al., 1987, Kenyon et al., 2008, Mulvaney et al., 2010). The high digestibility of brassica crops (Kirkegaard et al., 2008, Barry 2013) and potential for high liveweight gain of 100-200g/d as observed on winter-spring grazed canola (Sprague et al., 2014) could negatively impact on reproductive performance. It is also unknown if spring-sown canola will reliably stay vegetative through summer and autumn in high rainfall environments. The objective of this research was therefore to investigate the capacity of spring sown canola to boost ewe lamb growth and reproduction.

Methods

Seven forage treatments were sown in spring 2013 in a randomised complete block (RCB) design. The forage treatments were; 1). canola (cv. Hyola 971CL), 2). canola (cv. Taurus), 3). forage brassica (cv. Winfred), 4). lucerne (cv. StaminaGT6), 5). chicory (cv. Puna II), 6). plantain (cv. Tonic) and 7). perennial ryegrass+pellet supplement (cv. Banquet II) (control). Plots were 1 ± 0.1 ha in size. The plots were grazed by 8-9 month old maternal composite ewe lambs for a four week pre-joining period (25th March-23rd April 2014) followed by a six week joining period (23rd April-5th June 2014) using natural mating with maternal composite rams. On 25th March 2014, 288 ewe lambs were allocated based on stratification for liveweight, condition score, sire syndicate and birth type (single or twin born). Stocking rate was calculated using the

GrazFeed modelling program (Freer et al., 1997). Stocking rate was based on the quantity and nutritive value of the feed on offer, for ewes to achieve a predicted liveweight gain of 150 g/d for 10 weeks. The perennial ryegrass treatment included a pellet supplement with 9.8 MJ ME/kgDM and 11.6 %CP. Rams were randomly allocated to plots on 23rd April 2014 at one ram per plot. The rams were fitted with crayon harnesses to record mating activity and were rotated fortnightly using a restricted randomisation within replicate, such that all plots used three different rams over the mating period. Liveweight and condition score (CS) were measured fortnightly and pregnancy status was measured by ultrasound on 14th July 2014. Pre-grazing feed on offer was measured using calibrated visual assessments. On 26th August 2014 the canola was cut for silage. There were, therefore, three canola sub treatments: 1). ungrazed, 2). grazed during autumn and 3). grazed during autumn and winter and then cut for silage. All canola sub treatments were harvested on 18th-19th November 2014, after being assessed for ripeness, by taking two quadrat cuts, each 1.2m^2 per plot. A subsample of 10 plants was taken from these samples to determine yield components. The remaining bulk sample was dried at 40°C and then threshed using an electric thresher. An aspirator was used to further separate the grain and non-grain components. Analysis of variance with a RCB model was performed using plot means in GenStat® Release 14.1 VSN International, Hemel Hempstead, UK (2011).

Results

The canola did not differ (P>0.05) in feed on offer from the Winfred on any date, except for 17-Apr when the Taurus had lower (P<0.05) feed on offer than the Winfred but not the Hyola971CL (Table 1). The canola varieties and the Winfred had higher (P<0.05) feed on offer levels than the lucerne, chicory and plantain on all sampling dates, except 5-May and 19-May. The canola and the Winfred did not differ (P>0.05) in feed on offer from the perennial ryegrass+pellet on any sampling date, except 24-Jan and 12-Feb when the brassica treatments had 1.6-2.3 t DM/ha more feed on offer than the perennial ryegrass. The lucerne, chicory and plantain did not differ (P>0.05) in feed on offer on all but two sampling dates. Feed on offer from the perennial ryegrass was higher (P<0.05) than the lucerne, chicory and plantain over the March-April period, but during January and February these species did not differ (P>0.05) and in July the plantain had higher (P<0.05) feed on offer than the perennial ryegrass.

Table 1. Feed on offer (kg DM/ha) during January and February 2014 (ungrazed, pre-allocation), pre-grazing throughout the experiment (March-May 2014) and in mid-winter (ungrazed since 5th June 2014).

	Pre-allocation		Pre-grazing for each stock move					Winter
Treatment	24-Jan	12-Feb	24-Mar	7-Apr	17-Apr	5-May	19-May	2-Jul
Hyola 971	4162	3565	3639	3063	2385	1395	1305	3695
Taurus	3916	3499	3857	2565	1977	1293	1184	3362
Winfred	3824	3968	3612	2777	2877	1433	1371	3949
Lucerne	1940	1946	1297	992	679	936	558	1045
Chicory	2260	1445	1369	1302	472	934	798	1078
Plantain	1628	1416	1048	932	675	1175	1212	2050
Ryegrass+Pellet	2211	1689	2941	2679	2177	1251	1288	1589
LSD (5%)	644.4	467.7	800.7	645.8	613.4	425.4	535.0	1585.0
P=value	<0.001	<0.001	<0.001	<0.001	<0.001	0.121	0.040	0.002

Liveweights and CS did not differ (P>0.05) between treatments on any sampling date, but the p-value on 5th June 2014 was 0.06, with the canola and Winfred ewes being 49.0-51.0 kg while the perennial ryegrass+pellet ewes were only 44.0 kg (Table 2). Between allocation and the start of joining, liveweight gain of ewes on canola and Winfred did not differ (P>0.05) from the other treatments, except for the Taurus canola which had higher (P<0.05) daily liveweight gain than all other treatments except the chicory and plantain. During joining, liveweight gain of ewes on canola or Winfred were higher (P<0.05) than ewes on the perennial ryegrass+pellets and the chicory, but did not differ (P>0.05) from the other treatments.

There were no significant differences (P>0.05) in conception rate between treatments, with 258 of the 288 ewe lambs joined conceiving (89.6%) (Table 3). Forage treatment had a marginal effect on reproductive rates (P=0.059). Reproductive rates from the Hyola971CL, Taurus and Winfred were 42%, 54% and 24% higher than the perennial ryegrass+pellet treatment.

Table 2. Liveweight (kg) and condition score at allocation (25th March 2014), start and end of joining (23rd April 2014 and 5th June 2014), with liveweight gain (g/d) between allocation and start of joining and between start and end of joining.

	25-Mar-14		23-Apr-14		5-Jun-14		Weight gain	Weight Gain
Treatment	Wt	CS	Wt	CS	Wt	CS	(pre-joining)	(joining)
Hyola 971	38.7	3.1	42.9	3.3	49.2	3.4	145	147
Taurus	39.6	3.2	45.3	3.4	51.0	3.5	240	132
Winfred	38.3	3.1	43.1	3.3	49.0	3.5	166	137
Lucerne	39.3	3.1	44.1	3.2	46.3	3.3	163	51
Chicory	38.7	3.1	45.0	3.3	46.1	3.3	215	27
Plantain	39.0	3.1	44.0	3.2	48.3	3.4	205	101
Ryegrass+Pellet	38.6	3.0	43.9	3.1	44.0	3.2	184	2
LSD (5%)	1.78	1.70	2.15	1.89	4.41	2.47	55.06	67.62
P=value	0.78	0.84	0.24	0.09	0.06	0.38	0.027	0.001

Table 3. Average conception rate (Proportion of ewes joined that conceived) and average reproductive rate (number of foetuses per ewe joined).

Treatment	Conception rate (Proportion of ewes joined that conceived)	Reproductive rate (No. foetuses per ewe joined)
Hyola 971	0.89	1.46
Taurus	0.95	1.59
Winfred	0.86	1.28
Lucerne	0.96	1.51
Chicory	0.95	1.44
Plantain	0.84	1.29
Ryegrass+Pellet	0.85	1.03
LSD (5%)	0.10	0.35
P-value	P=0.085	P=0.059

Grazing the canola during autumn resulted in no canola yield penalty relative to the ungrazed control (P>0.05). Grazing the canola during winter and then cutting the canola for silage did however result in significant canola yield penalty (P<0.05), with canola yields in the silage plots reduced by approximately 60% relative to the ungrazed control. There were no statistical differences in the number of primary branches between the canola sub-treatments (P>0.05), however, the ungrazed control canola had fewer (P<0.05) secondary branches compared to the autumn grazed and ensiled canolas (Table 4).

Table 4. Grain yield (t /ha), No. of primary and secondary branches from spring sown canola that was ungrazed, grazed during autumn or grazed during autumn and winter then cut for silage.

Grazing Treatment	Grain yield (t /ha)	No. of primary branches	No. of secondary branches
Ungrazed	2.46	4.33	4.97
Aut grazed	2.24	4.29	7.48
Aut/Win grazed+silage	0.97	4.15	7.05
LSD (5%)	0.62	0.51	1.30
P-value	<0.001	0.846	<0.001

Discussion

The canola and forage brassica had higher feed on offer levels than lucerne, chicory and plantain throughout most of the experiment and also had higher feed on offer than the perennial ryegrass during January and February 2014. Previous research has indicated that summer Brassica crops (B. napus and B. campestris subsp. Rapifera and Oleifera) in south west Victoria can produce between 4.2-5.4 t DM/ha (Chin et al., 1993; Hopkins et al., 1992). Our research has shown that spring-sown canola crops can produce between 3.4-4.1 t DM/ha of feed on offer during summer and this feed can be retained into autumn to provide a source of accumulated green forage for joining ewes. The lucerne, chicory and plantain in our research produced lower levels of feed on offer than is their potential in this environment, with previous research indicating that established lucerne and chicory swards can produce 1.5-3.0 t DM/ha during the summer and autumn period (Ward et al., 2013). It is likely that the recent establishment, wet conditions during sowing, which resulted competition from weed species, followed by drier than average conditions throughout December 2013 to March 2014, resulted in the feed on offer potential of the lucerne, chicory and plantain not being realised.

At the start of joining, the liveweight and CS of the ewe lambs did not differ (P>0.05) between forage treatments, but during the joining period ewe lambs on the canola and Winfred had higher daily liveweight gains than ewe lambs on the perennial ryegrass+pellet treatment. Previous research has shown that very high levels of nutrition can negatively affect the conception rates of ewe hoggets (Mulvaney et al., 2010; Kenyon et al., 2008). Kenyon et al., (2008) compared ewe hoggets with liveweight gains of 134 and 223 g.d, while Mulvaney et al., (2010) compared ewe hoggets with liveweight gains of 153 and 208 g.d. Both studies found that a higher proportion of the high liveweight gain ewes did not conceive in the first cycle, but there was no difference in overall pregnancy scanning data or the percentage of hoggets that subsequently lambed. Our research, with weight gain between 132-147g.d. during joining, has indicated that ewe lambs can be safely joined on spring sown canola and Winfred forage brassica, with these green forages resulting in higher liveweight gains and improved reproductive rates relative to perennial ryegrass+pellet supplement ewes.

Conclusion

Ewe lambs can be safely joined on brassica crops during autumn to produce a high reproductive rate than ewes being fed perennial ryegrass and pellet supplement. Feed on offer and nutritive value of the canola cultivars were similar to Winfred forage brassica and consequently the liveweight gains and reproductive rate from ewes grazing canola were also similar to Winfred forage brassica. . Grazing canola during autumn results in no canola yield penalty relative to an ungrazed control. But further grazing of canola during winter and then cutting the canola for silage results in significant yield penalties. Further research is required into the vernalisation requirements of spring sown canola with canola at Hamilton showing evidence of unseasonal reproductive development. Sowing in spring also presents establishment risks associated with failed spring rains and increasing temperatures.

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Changed recommendations for the use of phalaris on acid soils

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Abstract
Phalaris (*Phalaris aquatica* L.) has been cultivated in Australia as a forage grass for over a century. Since the 1970's it has developed a reputation for being sensitive to soil acidity with conventional wisdom typically advising against its use on acid soils. However, several recent studies have called this view into question and have prompted a revision of the recommendations for the use of phalaris on acid soils. The release of new phalaris cultivars, first with cv. Landmaster in 1996 and later cv. Advanced AT in 2008, which have demonstrated superior tolerance to aluminium (Al) toxicity needs to be acknowledged. Yet, even prior to these developments it was evident that phalaris performance on acidic soils far exceeded contemporary expectations. We now have documented evidence of phalaris persisting in the field beyond pH and Al thresholds at which it is deemed suitable, and of phalaris persisting significantly better in strongly acid soils than species perceived to be highly tolerant of acidity, such as cocksfoot (*Dactylis glomerata* L.). Indeed, phalaris is endemic in many acid soil environments across the Tablelands of south-eastern Australia. It is suggested that phalaris should be considered for inclusion in new plantings on acid soils not only for its acid tolerance, but also for its drought tolerance which increases the resilience of pasture swards. Of course, any new plantings of phalaris in strongly acid soil environments should always use more tolerant cultivars following lime application. However, being a deep-rooted species, phalaris requires adequate soil nutrition and depth, and is less well suited to shallower soils which may also be acidic.

Key words
Aluminium toxicity; cocksfoot; drought; persistence; Landmaster; Advanced AT; soil depth

Introduction

Phalaris is one of the most productive and drought-tolerant pasture grasses used for livestock production on permanent grazing lands of south-eastern Australia. However, during the 1970's it developed a reputation for being sensitive to acidic soils and in particular to aluminium (Al) toxicity (Cregan 1980). Field observations were supported by experiments in solution culture which demonstrated that phalaris was more sensitive to Al toxicity than species such as cocksfoot (Culvenor *et al*. 1986). Lime experiments conducted in pots (Helyar and Anderson 1971) and in the field (Ridley and Coventry 1992) showed phalaris to be more responsive to lime than other more tolerant species adding weight to the argument that phalaris was less suited to acidic soils than other commonly used pasture species. A consequence of this collective experience is that agronomy recommendations typically advocate against the planting of phalaris on strongly acid soils due to its perceived poor adaptation (e. g. Anon. 2004).

However, the perception that phalaris is unsuitable to highly acidic soils seems counter-intuitive given that its area of adaptation in south-eastern Australia, usually in higher rainfall (600+ mm) Tablelands environments, coincides with a landscape that is renowned for high levels of soil acidity (Scott *et al*. 2000). More recent experiments conducted by the present authors have cast doubt over the wisdom of conventional recommendations suggesting that phalaris may indeed be a wise choice for some acid soil environments, particularly given the recent development of more acid/Al tolerant phalaris cultivars available on the Australian commercial market since 1996. The current overview paper aims to synthesise key findings from a range of recent experiments with a view to revising recommendations for the use of phalaris on acid soils.

Field experiments

The need to amend recommendations for the use phalaris on acid soils is highlighted by two field experiments conducted from 2004-2008 which showed phalaris persisting on acutely acidic soils under drought where more tolerant species failed completely. In this context it implies that conventional recommendations are in some instances leading to reduced resilience of improved pastures and actually

costing growers money. The first experiment was conducted on an acutely acidic soil (pH_{CaCl2} to 4.1 with Al saturation comprising up to 42% of the effective cation exchange capacity in the surface 0.4 m) near Goulburn, NSW (Hayes *et al*. 2010) and the second experiment was conducted at Gerogery, NSW, where soil in the surface 0.2 m had a pH_{CaCl2} as low as 4.1 with Al saturation up to 23% (Hayes *et al*. 2015). Both experiments included phalaris cv. Landmaster and cocksfoot. cv. Currie, but tall fescue (Festuca arundinacea Schreb.) cv. Demeter at the Goulburn site and cv. Fraydo at the Gerogery site. Tall fescue and particularly cocksfoot are both considered more tolerant of soil acidity than phalaris, but in both cases in contrast to phalaris, failed to persist, despite the acidic nature of both soils. Relative persistence was determined by assessing basal frequency on two 1 m×1 m fixed quadrats (divided into 100 squares) per plot, where the number of squares containing the bases of a sown perennial species was counted (Table 1). In both instances, phalaris responded positively to lime.

Table 1. Basal frequency (%) of phalaris, cocksfoot and tall fescue grown with (+L) and without lime following a period of drought at Goulburn and Gerogery. (Adapted from Hayes et al. 2010; 2015)

Site	Phalaris	Phalaris +L	Cocksfoot	Cocksfoot +L	Fescue	Fescue +L
Goulburn	40.8 [a]	55.2 [a]	0.8 [b]	9.2 [b]	2.0 [b]	13.2 [b]
Gerogery	12.0 [ab]	19.2[a]	3.8 [c]	6.4[bc]	5.0 [bc]	5.8 [bc]

Values at each site followed by the same superscript letter are not significantly different at P=0.05.

The explanation for the superior performance of phalaris at these sites is likely due to its inherent tolerance of drought and soil acidity. Both sites experienced severe drought conditions shortly after establishment in 2006 where drought was widespread across much of southern Australia. In both cases the basal frequency of phalaris increased in response to more favourable seasonal conditions in later years (data not shown). At both sites the phalaris swards were able to withstand periodic drought and recover, whereas the cocksfoot and tall fescue failed to persist.

Solution culture experiment

A solution culture experiment was conducted in 2014 to assess the relative tolerance of phalaris, cocksfoot and tall fescue seedlings to Al and Mn toxicity (Song *et al*. 2015). Phalaris genotypes were found to be more sensitive to Al toxicity than cocksfoot genotypes in particular, with the decline in root length from the 0μmM treatment compared to the 300 mM treatment being greater in phalaris and tall fescue. However, the absolute root length of phalaris remained at least as large as that of cocksfoot or tall fescue (Table 2) and root length of phalaris was greater at the nil Al concentration (i.e. more responsive to amendment).

Table 2. Seedling root lengths (mm) of phalaris, cocksfoot and tall fescue at 5 concentrations of Al, and the decline (%) from nil to maximum Al concentration after 21 days growing in solution culture (Adapted from Song et al. 2015)**.**

Species	Root length (mm) at 5 concentrations of Al in solution					
	0μM	50μM	100μM	200μM	300μM	%Decline
Phalaris	237.9	141.4	128.5	61.6	43.5	81.7
Cocksfoot	134.7	95.9	90.5	48.7	44.6	66.9
Tall fescue	171.4	102.7	84.6	39.1	30.7	82.1
$LSD_{0.05}$	25.85	n.s.	n.s.	n.s.	n.s.	14.22

Advances in breeding Al tolerant phalaris genotypes

Improvement in acid soil tolerance became a priority in phalaris breeding after the reports of sensitivity to soil acidity in the 1970's. Landmaster was released in 1996 after selection for Al tolerance in solution followed by several cycles of selection at field sites with skeletal, moderately acidic soils. Simultaneously, the discovery that *P. arundinacea* was more Al-tolerant than *P. aquatica* led to a program of hybridisation and backcrossing between the two species to transfer higher Al tolerance into a *P. aquatica* background (Oram *et al*. 1990). Cycles of selection at highly acidic field sites resulted in the release of Advanced AT in 2008. Studies in Al solution demonstrated Al tolerance in the order: Advanced AT > Landmaster > Holdfast > Sirosa, Australian II (Requis and Culvenor 2004; Culvenor 2008). Establishment after a spring sowing at a strongly acid (pH 3.9) field site at Chiltern, Victoria, closely followed this order presumably reflecting success in growth of deep roots into a drying subsoil high in Al, but not when sown in autumn in a year with good rainfall (Culvenor *et al*. 2004). The resultant hypothesis that the effect of differential Al tolerance in phalaris on field performance

was dependent on seasonal moisture and sowing time was confirmed (Culvenor *et al*. 2011). Advanced AT and Landmaster were shown to establish and persist better than other cultivars on strongly acid soils (pH 3.9-4.2) but Advanced AT was superior in establishment to Landmaster when sown in a drought year. Haling *et al*. (2010) also showed better root growth by Advanced AT than Sirosa in a soil with pH 3.9 and Al ($CaCl_2$ extractable Al) of 18 µg/g indicating that Advanced AT was similar in Al tolerance to cocksfoot. A caveat to this observation is that cocksfoot may still be better adapted than phalaris to low soil fertility which can coincide with acidity. The higher seedling vigour of Sirosa partly compensated for its greater sensitivity to Al.

Thresholds of phalaris on acid soils

The interaction of environmental factors with Al tolerance clearly complicates the setting of thresholds for the use of phalaris. In a drought year in the field study of Culvenor et al. (2011), establishment was related to Al tolerance at sites with pH in the range 3.9-4.2, Al_{CaCl2} 15-25 µg/g and Al saturation 30-55% of CEC to 0.50 m depth. In contrast, all phalaris cultivars established well at a site where pH averaged 4.4 and Al_{CaCl2} ranged from 3-7 µg/g and Al saturation from 12-22 % to 0.50 m depth. It was concluded that Advanced AT can be established more reliably than Landmaster in soils where a substantial proportion of the depth to 0.50 m was pH 4.2 or less and Al saturation >30%. All cultivars should tolerate exchangeable Al of 20% of CEC and pH >4.2. Advanced AT and probably Landmaster should still be suitable where layers with exchangeable Al of 30-50% and Al_{CaCl2} of 15 µg/g occur in the upper 0.50 m but with the recognition that they may be able to tolerate higher levels of Al in restricted depth intervals. For example, phalaris established, produced and persisted well on a soil averaging pH 4.2 and Al saturation ranging from 28-62% to 0.50 m depth but $CaCl_2$ extractable Al averaging only 7 µg/g (Culvenor *et al*. 2007). Further consideration of Al_{CaCl2} as a measure of Al toxicity potential is warranted (Bromfield *et al*. 1983).

Effects of Al tolerance on persistence in the study of Culvenor *et al*. (2011) were parallel but smaller than those on establishment, and tolerance to grazing may be more important for persistence. Thus, both Advanced AT and Landmaster benefit significantly in persistence from rotational rather than continuous grazing at high stocking rates under good soil fertility (Culvenor and Simpson 2015). Culvenor *et al*. (2004) found that control cultivars and families related to Advanced AT persisted adequately on strongly acid soils if they established well although survival was lower on a low fertility soil derived from sedimentary material on the Southern Tablelands. They concluded that nutritional factors, such as soil P buffer capacity, were clearly important for phalaris on acid soils and require closer attention. Analysis of soil to depth (≥0.50 m) is also important since acidity at depth can influence phalaris persistence. Culvenor *et al*.(2004) found that persistence was excellent on a soil where average pH of 4.0, Al_{CaCl2} of 16 µg/g and Al saturation of 41% were restricted to the upper 0.30 m with pH increasing to 4.5-5.2 from 0.30-0.60 m depth. However, persistence was lower on a soil with less available Al in the upper 0.30 m but in which strong acidity extended to at least 0.60 m (pH 4.0, Al_{Ca} 16 µg/g, Al saturation 40%).

Discussion and conclusion

The complete failure of 'acid-tolerant' species, such as cocksfoot and tall fescue, but superior persistence of the 'acid-sensitive' phalaris at highly acidic field sites at Goulburn and Gerogery highlights the need to challenge conventional wisdom that phalaris is not suitable for acid soils. Indeed, phalaris has proven its resilience on a range of acidic soils. The current recommendations derived from previous solution culture and liming experiments were merely reflecting the highly responsive nature of this species which could achieve greater increases in yields than other species such as cocksfoot. This high level of response should not be interpreted as an indication of poor suitability to an acidic or high Al soil environment. Results from the latest solution culture experiment (Song *et al*. 2015) suggested that the increased 'sensitivity' of phalaris genotypes to Al toxicity did not necessarily infer lower 'suitability' to acid soil environments. A phalaris seedling with a root length of 44 mm is likely to have at least as great a chance of accessing water and nutrients in a soil environment as a tall fescue seedling with a root length of 31 mm. Indeed, it might be argued that at lower Al concentrations, longer seedling root lengths in phalaris may give that species an advantage over tall fescue or cocksfoot in less extreme acidic soil environments (Table 2). Genetic improvement of phalaris since the 1970's has led to the development of more Al-tolerant cultivars, particularly Landmaster and Advanced AT. These cultivars have extended the acid-soil thresholds at which phalaris might be reliably grown, with good establishment achieved at pH 4.2 and >30% Al. The majority of newly sown pastures would fall within these thresholds meaning that phalaris is now a viable candidate for most new perennial grass plantings.

We recommend that phalaris cultivars such as Advanced AT or Landmaster be used where soil is acidic. Use of these cultivars is anticipated to guard against establishment failure in drier than average seasons as

supported by the experience of Culvenor *et al*. (2011). For optimal results, lime should be applied prior to the establishment of newly sown pastures on acidic soils, thereby also limiting risk of establishment failure but also capitalising on the highly responsive nature of phalaris to lime. We recognise that persistence of these phalaris cultivars is further improved by maintaining high levels of nutrition in soils and by imposing a rotational grazing management regime. Phalaris is a deep-rooted species which requires adequate soil nutrition and depth, and is less well suited to shallower soils which may also be acidic.

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Dual-purpose crops: comparison of maternal systems grazing canola or wheat during late pregnancy and lambing then lucerne-based pasture until weaning

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Dual-purpose crops can reduce winter feed gaps and allow an increase in farm stocking rates on mixed-farms. This study sought to compare the effect of inclusion of dual-purpose crops on livestock systems producing meat only compared with a system producing meat and wool. Six plots (1.86ha) were sown to either dual-purpose wheat or canola in April 2014 in a replicated design. White Dorper ewes joined to either White Suffolk (WSD) or White Dorper (Dorper) rams, and Merino ewes joined to White Suffolk (WSM) rams were scanned in lamb on 15 May and allocated to plots on 19 June at a stocking rate of 13 ewes/ha, with a minimum of six ewes of each genotype per plot. Lambing commenced on 13 July and lamb birth weights were recorded. Ewes and lambs grazed lucerne-based pasture from 12 August until weaning on 29 September when all ewes and lambs were weighed. Crude protein levels were initially higher in wheat, but were lower at the conclusion of grazing; digestibility was initially similar between crops but declined in wheat during the grazing period; and NDF was always lower in canola compared to wheat (all $P<0.001$). Ewe liveweights were significantly ($P<0.001$) heavier when grazing wheat compared to canola at the end of crop grazing, but there was no significant difference at weaning. The interaction of crop and lamb genotype was significant for lamb weaning weights ($P=0.027$) with White Dorper lambs from the wheat treatments being significantly lighter than from the canola treatment.

Key words
Mixed farming, crop grazing, reproducing ewes, White Dorper, Merino.

Introduction

Dual-purpose crops allow farmers to spread sowing dates, provide additional feed for grazing by livestock in late-autumn and winter, and produce grain yields similar to ungrazed spring cultivars given good management and favourable seasonal conditions. The ability to graze late-pregnant and lambing ewes on crops provides flexibility to the system, providing high quality feed to ewes at a time of high energy demand when pasture supply is often limiting. Ewes can be safely grazed on dual-purpose wheat during late-pregnancy and lambing (McGrath et al. 2015); however the suitability of dual-purpose canola for grazing by reproducing ewes has not been assessed. Returns for a livestock enterprise consisting of Merino ewes joined to a terminal sire and grazing lucerne-based pasture may be increased by allowing ewes to graze a dual-purpose wheat crop (McGrath et al. 2014). Non-wool breeds of sheep such as Dorper and White Dorper breeds have been recently introduced to Australia and more production data for these breeds is required for feedbases that include dual-purpose crops and lucerne. The aim of this study was to compare ewe weight changes and lamb weaning weights when ewes grazed either dual-purpose wheat or dual-purpose canola during late-pregnancy and lambing followed by lucerne-based pasture until weaning. In addition the production to weaning from maternal systems based on Merino or White Dorper ewes on these feedbases was compared.

Methods

Paddock preparation

Plots (1.86 ha) were sown to dual-purpose crops in 2014 in a replicated complete block design in a paddock previously sown to wheat at Wagga Wagga, NSW. Existing stubble was burnt in March 2014. Dual-purpose canola (Hyola 971CL) was sown on 8 April at a sowing rate of 4.1 kg/ha and a fertiliser rate (MAP) of 81 kg/ha. The canola was sprayed with Elantra extreme (200 g/L quizalofop-P-ethyl; 190ml/ha) on 17 May to control grass weeds. Dual-purpose wheat (EGA Wedgetail) was sown on 9 April at sowing rate 80 kg/ha and fertiliser rate (MAP) 80kg/ha. The wheat was sprayed with Monza (750 g/kg sulfosulfuron; 25g/ha) on 17 May to control grass weeds.

Plant establishment counts were made on 9 May. Feed on offer (FOO) was measured at the start and finish of grazing using the method of Haydock and Shaw (1975), with a minimum 17 calibration cuts per species and 60 visual measurements across two transects in each plot. Pluck samples were collected on three occasions during crop grazing, with samples dried at 70ºC and tested for digestible dry matter in organic matter (DOMD), crude protein (CP) and neutral detergent fibre (NDF) using near-infrared spectroscopy in a commercial laboratory, with wet chemistry validation on 10% of samples.

Sheep management

White Dorper and Merino ewes were joined on lucerne pasture from 17 February to 31 March 2014. Fifty four Merino ewes (born 2008) and 49 White Dorper ewes (born 2011) were joined to four White Suffolk rams (lamb genotype designated WSM and WSD respectively), and 49 White Dorper ewes were joined to two White Dorper rams (designated DD). Ewes were vaccinated (5-in-1) on 23 April and 30 May, and worm egg counts identified that drenching was not required. Ewes were scanned as single, twin or empty on 15 May.

Ewes were blocked by scanning as single or twin and body condition scored (BCS) for allocation to treatment. Initially 18 ewes of each lamb genotype were allocated per treatment (11 single DD, 7 twin DD; 9 single WSD, 9 twin WSD; 9 single WSM, 9 twin WSM) with numbers balanced by replicate. An additional four pregnant and two dry non-experimental ewes were allocated per plot due to high biomass. Therefore 24 ewes were grazing each plot at the commencement of grazing (stocking rate 13 ewes/ha). Due to leaf availability in the canola treatment the two dry ewes in replicate one were removed from the canola treatment on 8 July, and from replicate two and three on 24 July. Ewes were moved to lucerne plots (2.1ha) on 12 August. Due to declining availability of lucerne in plots, sheep in all plots were combined into a single mob on 12 September, and continued to graze an alternate lucerne and clover pasture until weaning on 29 September.

Ewes grazing wheat had access to a loose-lick supplement consisting of magnesium oxide, stock lime and salt in a 2:2:1 ratio (as fed). No supplement was provided to ewes grazing canola, based on the recommendations of Dove et al. (2012).

Lambing commenced on 13 July, with all lambs weighed and tagged within 24 hours of birth and ewe tag noted; lambs were weighed again at weaning on 29 September. Ewe weights were also recorded at the start and finish of the experiment and on three interim occasions corresponding to three weeks after the commencement of grazing (all ewes still pregnant; 8 July); the end of crop grazing (12 August); the end of grazing individual plots of lucerne (12 September); and weaning (29 September).

Statistical analysis

Ewe and lamb data for dry ewes, ewes giving birth to triplets and triplet-born lambs was excluded from the analysis. Linear mixed models in Genstat 16th Edition (VSNi, UK) were used to analyse data. The reduced fixed model for ewe liveweight included starting weight and whether the ewe was still pregnant or had lambed as co-variates, with random model replicate/plot/ewe/date. The reduced fixed model for lamb weaning weights included rearing status (single; twin-born, single-raised; twin-born, twin-raised) and lamb age as co-variates, and replicate/plot as random effects.

Results

Wheat and canola

Mean plant establishment counts (± s.d.) were 134 ± 38 plants/m^2 for wheat and 49 ± 17 plants/m^2 for canola. The interaction between treatment and date was significant for FOO (P=0.009); FOO was significantly higher in wheat compared to canola crops at the start of grazing (2607 v. 2297 kg DM/ha) but did not differ significantly at the end of grazing (1487 v. 1285 kg DM/ha).

The interaction of date and crop was highly significant for CP, DOMD and NDF (all P<0.001). CP concentrations in wheat were initially higher than canola but were lower at the conclusion of grazing. DOMD was similar between crops early in the grazing period, with digestibility of wheat declining throughout the grazing period, while canola remained more digestible. The NDF content of wheat was higher than canola and increased during the grazing period, while NDF content of canola pluck samples did not

differ significantly between sample dates (Table 1).

Ewes
Lambing was characterised by a high number of ewes requiring assistance at lambing (21% assisted births), associated with the high BCS of ewes at the commencement of lambing (due to excellent seasonal conditions through autumn). Four ewes died during the experiment and were autopsied; one Merino (grazing wheat) and one White Dorper (grazing canola) ewe died on 21 July from likely toxaemia/septicaemia associated with mastitis; one White Dorper ewe (grazing canola) died on 6 August from acute peritonitis, secondary to uterine rupture; and one White Dorper ewe (grazing lucerne) died on 4 September from suspected enterotoxaemia.

Ewe liveweight
The interactions of number of lambs born per ewe, ewe breed and crop grazed were significant with date (Table 2). Ewes grazing wheat were heavier than ewes grazing canola at the end of crop grazing (12 August) but not at weaning (29 September).

Lambs
The birth weight of lambs was not affected by the crop grazed by ewes (P=0.835). Differences in mean birthweights of DD (5.0 kg), WSD (5.3 kg) and WSM (5.2 kg) approached significance (P=0.061; s.e.d. = 0.1 kg). Birth weight of single born lambs were significantly heavier than twin-born lambs (5.4kg v. 4.8kg; P<0.001) and birth weight of male lambs was significantly heavier than female lambs (5.3kg v. 5.0kg; P=0.018).

There was a significant interaction between crop and genotype for lamb weaning weights (P=0.027; Table 3), with Dorper lambs being significantly lighter at weaning from the wheat treatment compared to the canola treatment, but there were no significant differences between treatments for WSD or WSM lambs.

Discussion
Dual-purpose wheat and canola both represent high value forages for sheep, with high digestibility and crude protein content. The NDF content of canola was lower than wheat. Low NDF content is common in brassica species (Westwood and Mulcock 2012), and guidelines for grazing brassicas recommend supplying roughage to livestock to increase fibre intake (Ayres and Clements 2002). We did not feed additional fibre to ewes grazing canola and there were no apparent adverse effects. Further research is required to determine if reproducing ewes grazing dual-purpose canola will benefit from supplementation with additional fibre.

The ability of ewes to safely graze dual-purpose canola during late pregnancy and lambing may present opportunities for mixed-farms. Modelling has recently demonstrated that allowing ewes to graze dual-purpose wheat crops allows stocking rate to be increased when lambing in autumn, but did not change the optimum time of lambing (defined as the lambing month achieving the highest median gross margin over the long-term) was still June for a lucerne-based livestock system at Wagga Wagga, NSW (McGrath *et al*. 2014). Dual-purpose canola may be better suited to earlier grazing than dual-purpose wheat, and grazing the two crops in sequence may widen the grazing window (Sprague *et al*. 2015). The implications for lambing time, stocking rates and producer returns of allowing reproducing ewes to graze both crops in sequence needs to be further explored.

No previous studies have compared lamb growth rates to weaning when ewes lamb on dual-purpose crops. The reason for the lower weaning weights of White Dorper lambs born on dual-purpose wheat is unclear, but may be related to the declining digestibility of this crop relative to canola later in the grazing period. The lower weaning weights (age adjusted) of White Dorper lambs compared to WSD and WSM may reflect the limited genetic background of the White Dorper sheep in Australia, given the recent introduction of the breed. The current study demonstrates the potential of using a terminal sire in lamb production systems that include White Dorper ewes to increase weaning weights of lambs in a Dorper-based system.

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Table 1. Nutritive value of wheat and canola forage

	crop	date		
		26-Jun-14	11-Jul-14	14-Aug-14
Crude Protein (% DM)	wheat	25.7	22.8	14.5
average sed = 0.7	canola	22.8	19.5	18.7
DOMD (% DM)	wheat	85.7	77.7	73.0
average sed = 0.7	canola	86.3	83.0	83.0
NDF (% DM)	wheat	40.3	46.7	48.3
average sed = 0.1	canola	26.3	26.7	27.0

Table 2. Table of effects on ewe liveweight for interactions with date

category		date					sed	P-value
		17-Jun	8-Jul	12-Aug	12-Sep	29-Sep		
number lambs	single-bearing	76.9	83.0	89.8	83.8	84.3	1.0	<0.001
	twin-bearing	77.4	83.9	82.6	74.8	75.5		
genotype	White Dorper	77.2	84.1	88.7	79.8	80.4	1.0	<0.001
	Merino	77.1	82.7	83.7	78.8	79.3		
crop	canola	76.9	82.4	84.7	79.3	80.3	1.0	0.001
	wheat	77.4	84.5	87.7	79.4	79.5		

Table 3. Mean weaning weight (kg/hd) of lambs born in 2014 (average SED = 0.1 kg)

crop	genotype		
	Dorper	WSD	WSM
canola	29.4	30.8	28.5
wheat	26.5	30.9	28.8

Utilisation and feed quality of two forage Brassica (*Brassica napus*) cultivars

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Abstract
Brassica (*Brassica napus*) and lucerne (*Medicago sativa*) are common forage crops for finishing lambs particularly in summer dry environments. Anecdotal evidence suggests these finishing feeds have been associated with negative effects on lamb flavour without robust supportive evidence. An experiment was designed to objectively measure and characterise the differences in the flavour of lamb meat finished on different forage types. A trial in south-west Victoria was undertaken during the particularly dry 2012-13 summer on finishing crops including lucerne, perennial ryegrass (*Lolium perenne*) and two varieties of forage Brassica. 125 lambs were randomised to eliminate breed and sire effect and subsets of 25 animals grazed each treatment over a 6-week period. This paper briefly reviews recent work on the sheep meat texture and flavour experiment and reports further on forage Brassica utlisation and feed quality of different plant segments: whole plant; leaf (and petiole); and the higher, middle and lower fraction of stem.

Key words
Forage Brassica, quality, lucerne, utilisation

Introduction

Producers aim to achieve maximum live-weight gains and finish lambs as soon as possible before the summer-autumn feed deficit, or, will attempt to carry and finish lambs through this period. Common finishing forages used in the central highlands district of Victoria typically include perennial ryegrass (*Lolium perenne*), lucerne (*Medicago sativa*) or forage Brassicas i.e. rape (*Brassica napus*). Perennial ryegrass (often sown with companion clovers) can be ideal finishing forages in favourable environments, under irrigation or supplemented with grain. Lucerne is also a highly desirable option mainly due to its perennialilty, high protein, flexibility in grazing systems as either straight or mixed stands and increases in lamb carcass weight over ryegrass-sub clover pastures (Hall *et al*. 1985).

Forage rape is another common source for finishing lambs particularly in summer-dry environments (Barry 2013; Judson et al. 2013). As annually grown crops, they have traditionally been used to fill feed deficits and are generally spring sown in the central highland region because they are quick, productive, are of high feed value, are relatively tolerant to low rainfall and can respond very well to irrigation. Traditional forage turnips (*B. rapa*; syn. *B. campestris*) have been largely displaced by forage rapes (*B.napus*) due to quicker time to grazing, regrowth ability and better establishment under moisture deficit. The onset of pests such as diamondback moth (*Putella xylostella*) and white cabbage butterfly (Pieris brassicae) during dry periods remains an ongoing agronomic challenge. There are also significant differences between forage rape cultivars in quality, utilisation and lamb growth rates (Judson *et al*. 2013).

Anecdotally, forage Brassica has been associated with negative flavours or taints in lamb. Recommendations have been to have a 'washout' period on grain after being on Brassica crops (AgFacts NSW Report). A comprehensive pilot experiment was designed to assess the impact that different finishing forages have on lamb quality and flavour. Recent publications by Frank et al. (2014a, 2014b) used trained sensory panels and consumer data to characterise the relative impacts of finishing feed (forage Brassica, lucerne, and supplemented ryegrass) and genotype on grilled lamb quality. These workers found little evidence that any of the novel finishing feeds (forage Brassica and lucerne) produced unacceptable flavours or taints in lamb. In general, lambs with high eating quality breeding values had stronger flavour and better texture characteristics. This paper reports on some of the agronomic differences between the two rape varieties from the experiment by Frank *et al*. (2014a, 2014b).

Methods

Experimental site and treatments - The experiment was conducted at the PGG Wrightson Seeds Leigh Creek Research Station (37°56'S, 143°95'E) in the central highlands region of south-west Victoria. Soil

type comprises of deep red loam soils derived from basalt, with a mean annual rainfall of 705 mm and average daily maximum of 16.8°C and minimum 7.7°C. Treatments included two rape cultivars ('Titan' and 'Greenland'), lucerne and perennial ryegrass. The un-replicated lucerne and ryegrass crops were pre-existing stands sown in 2011 and 2012 respectively. Forage brassica seed was treated with Imazocloprid and sown at 4 kg/ha on 1st October 2012 with pre-spread MAP fertiliser (NPS: 10%; 21.9%, 1.5%).

Seasonal conditions - The site received below average rainfall (-31.5 mm/month) and higher average (+1.96°C/month) temperatures through-out the experimental period (data not shown). For the 3 months leading up to commencement of grazing, less than half of the long-term average rainfall was received with only 2.4 mm falling in January 2013. Temperatures varied above the long-term average with extended periods of hot, dry and windy conditions.

Animal allocation and treatments - CSIRO Animal Ethics Committee approval was granted prior to the arrival of lambs at the research station (#AEC 31592). Further information on lamb allocation and design is provided by Frank et al. (2014a). Briefly, 125 lambs were randomised to eliminate breed and sire effect and subsets of 25 animals grazed each treatment over a 6-week period.

Forage Brassica utilization - Pre-grazing mass for 7 day break allocations for both Brassica treatments was determined through pre-grazing dry matter harvests. Plants within five representative 1m^2 quadrants were harvested in grids across each treatment. Samples collected and dried at 80°C for 3 days to determine dry matter percentage and yield. Allocation was based on 2.5 kg/hd/day allowance, accounting for metabolic weight and wastage (0.5 kg/hd/day). Utilisation was determined by post-grazing dry matter sampling. Similar to pre-grazing mass determination, five 1m^2 quadrants of material (stem, leaf and trampled) were collected, dried and weighed to determine post-grazing dry matter percentage and yield. All dead material, soil and fecal matter were excluded and any contamination on remnant leaf or plant was washed off.

Feed quality - A subsample of 15 representative plant sizes within each quadrant was dissected into leaf (lamina and petiole) and stem, dried and leaf to steam ratio determined at every break. The stem was further divided into thirds (determined by length) of each stem section – top, middle and bottom. Ryegrass and lucerne samples were also collected (data not shown). All quality samples were dried at 60°C for 4 days and sent to DairyONE in Wisconsin (USA) and for wet chemistry analysis. Data was analysed by ANOVA repeated measure design with Statistix 9.0.

Results and Discussion

Significant forage quality differences were detected between both the Brassica treatments and within individual plant segments of those treatments (Table 1). The three stem components of 'Titan' (higher, middle and lower) were significantly greater ($P<0.05$) for Metabolisable Energy (ME) and significantly lower ($P<0.05$) in Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) than 'Greenland', with the exception in the lower leaf components for ADF.

Table 1. Quality of two forage brassicas treatments: ME, CP, ADF, NDF and TDN. Samples collected across three dates (16th January, 30th January and 14th February 2013) in different plant segments: whole plant; leaf and petiole (leaf); and the third higher, middle and lower fraction of stem. Means with the same letter following are not significantly different (P>0.05)

	ME	CP	ADF	NDF	(TDN)
Forage Brassica - components					
Greenland - whole plant	10.93^{cd}	21.50^{b}	25.00^{bc}	31.27^{c}	65.67^{bc}
Greenland – leaf	11.76^{a}	26.53^{a}	14.40^{e}	22.63^{d}	69.00^{a}
Greenland - stem (higher)	10.75^{de}	18.83^{cd}	23.70^{cd}	31.13^{c}	65.67^{bc}
Greenland - Stem (middle)	10.00^{gh}	16.23^{ef}	31.33^{a}	42.33^{ab}	62.33^{de}
Greenland - Stem (lower)	9.82^{h}	15.77^{f}	32.10^{a}	45.07^{a}	61.33^{e}
Titan - whole plant	11.39^{ac}	18.57^{cd}	15.20^{e}	20.30^{d}	69.33^{a}
Titan – leaf	11.67^{ab}	21.50^{b}	16.57^{e}	18.87^{d}	70.00^{a}
Titan - Stem (higher)	11.28^{ac}	19.57^{bc}	19.30^{de}	22.90^{d}	68.00^{ab}
Titan - Stem (middle)	10.68^{df}	18.37^{ce}	23.17^{cd}	31.73^{c}	65.33^{c}
Titan - Stem (lower)	10.39^{eg}	17.27^{df}	29.10^{ab}	36.13^{bc}	64.00^{cd}
lsd (0.05)	*0.50*	*2.22*	*5.04*	*7.57*	*2.43*

Considering the dry conditions, the two forage Brassica's still produced 5.2 t DM/ha (Greenland) and 4.6 ton DM/ha (Titan) pre-grazing yields at the first break (Table 2), 95 days after sowing. There was no significant difference (P>0.05) between pre-grazing yields in any break. Significant differences (P<0.05) in pre-grazing leaf percentage were observed in breaks 1, 3 and 5. Utilisation of the two Brassica cultivars increased from less than 30% in the first break, to greater than 80% by the last break (Table 2). Titan in the first two breaks had greater, but non-significant (P>0.05) utilisation and by Break 3 there was little difference. However, the fourth break showed Titan had significantly greater (P<0.05) utilisation by over 25% than Greenland. As utilisation is a measure of the percentage of the allocated feed actually consumed and has a considerable influence on feed intake, this is a key driver of animal performance. Differences in utilisation in the first two breaks, regardless of initial yield, could explain the quicker adjustment period and animal growth rates observed (data not shown). This phenomenon was also reported in detail by Judson *et al*. (2013). Differences in utilisation may also be directly attributable to plant architecture and components of quality (i.e. greater pre-grazing leaf versus stem segments). Whilst the lamb growth performance data was un-replicated, it indicated that lamb growth rate potential on the two forage Brassica treatments were greater than both the lucerne and the grain supplemented perennial ryegrass. From this study, forage Brassica proved a useful crop for finishing lambs in a dry summer environment providing high quality feed and utilisation differences between cultivars.

Table 2. Utilisation measurements of the two Brassica treatments 'Greenland' and 'Titan' at the 5 weekly breaks for pre-grazing dry matter (DM) yield; pre-grazing leaf percentage; and percentage utilisation of brassica crop.

		Break 1	Break 2	Break 3	Break 4	Break 5
Pre-grazing DM yield	Titan	4587	4536	5177	5029	5580
	Greenland	5243	5150	5194	4511	5495
	lsd (0.05)	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Pre-grazing leaf percentage	Titan	80.2	72.0	73.7	64.8	66.3
	Greenland	70.0	64.0	61.5	58.4	48.9
	lsd (0.05)	*7.6*	*n.s.*	*5.3*	*n.s.*	*6.35*
Percentage crop utilisation	Titan	25.0	40.0	48	75.4	81.7
	Greenland	4.3	35.0	54.6	47.2	67.8
	lsd (0.05)	*n.s.*	*n.s.*	*n.s*	*8.7*	*n.s.*

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Drawing together information and practice through integrated on-farm research

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Abstract
Connecting researchers in multi-disciplinary teams and bridging the gap between research outputs and end users is – or should be - a high priority for research and development projects. The results from a research for development project in southern Laos and other sources informed the knowledge sharing approach undertaken, using Focal Village (FV) sites to integrate the use of various technologies on-farm and within villages, in order to enhance systems level understanding and as sites for co-learning and extension. These sites represented the major agro-ecological zones identified in the project area. Using an agro-ecology typology approach provided a basis for site selection and integration of technologies, with a clear definition of the application domain of the knowledge generated, and of the integrated farming systems that may be possible within each. The integration of technologies at the farm and village level enhanced understanding of integration points and farming systems, while integration of planning and project management enhanced the effectiveness of project activities. Focal village sites had value as an integrating factor for project activities, providing a common location to work together, and thereby enhancing organisational integration. Working together across disciplines was a new experience, which benefitted from training, mentoring, planning and budget support.

Keywords
Research; development; integration; knowledge sharing

Introduction
Knowledge sharing approaches used by multi-disciplinary research projects are undertaken to connect researchers and to bridge the gap between research outputs and end users. The approaches undertaken depend on many factors, including technical application, research approach, bio-physical constraints and implementation. Methods for integrating research processes and outputs are necessary when working in diverse project teams, but such methods are often not initially clearly identifiable at project initiation, and there is no one approach that can be relevant in all situations. Instead, there is a need to draw on a range of skills, tools and approaches to achieve desired outcomes. Integration in research refers to the drawing together of different perspectives (e.g. disciplines) to improve overall understanding of a complex problem, and improve the application of this resulting knowledge (Bammer, 2006); this process is becoming increasingly important for multi-disciplinary research projects and programs. Too often, these projects are developed with the assumption that because they are multi-disciplinary, integration will be achieved automatically; however, integration does not just "happen", rather it is a complex process that needs to be planned carefully (Proctor et al., 2010) and assigned the same level of importance as other project activities. Useful approaches to integration may come from a range of sources, and there is a continued need to document relevant experiences in order to consolidate and distil common themes and practices (Gonsalves et al., 2005).

A multi-disciplinary research project on 'Developing improved farming and marketing systems in rainfed regions of southern Lao PDR' (hereafter referred to as 'the project'), funded by the Australian Centre for International Agricultural Research (ACIAR), was implemented in southern Laos from 2010 – 2014. The project was set up as a partnership between the National Agriculture and Forestry Research Institute (NAFRI) (the in-country project lead) and several international research organizations, and linked with provincial and district agriculture staff for implementation of on-farm research in eight districts. Five components worked across the farming system in crop agronomy, livestock, water and hydrology, socio-economics and marketing. The knowledge sharing component took on a 'boundary spanning', facilitative role in terms of coordinating with other components and external stakeholders for improved integration of project activities, capacity building and extension of project results. 'Boundary spanning' refers to those organisations or individuals that are committed to building bridges within a project team and or between the research community and the end user, and are accountable to all groups (Kristjansen et al, 2009).This paper describes the approach of the knowledge sharing component, in order to draw out general approaches to linking information and practice that may be used in subsequent projects.

Targeting technologies through Focal Villages

At the commencement of the project, each component's research activities were located in a range of geographical locations within the project's target districts. Focal Villages (FV) were identified to integrate the use of various technologies on-farm and within villages, in order to enhance systems level understanding and as sites for co-learning and extension. These villages were selected based on previous project activity, including baseline socio-economic surveys, other research activities, and level of accessibility. The use of FV as key project learning sites offered pathways for outscaling promising technologies. Targeting proactive farmers in progressive villages as a way of promoting uptake of high potential agricultural activities has been cited previously as a way of out scaling agricultural research in Laos (Alexander et al., 2010). The establishment of trials by farmers under local growing conditions is also an effective way to encourage acceptance of new technologies such as new crop varieties (Harris, 2011), and was valued by participating farmers and district staff for these reasons in this project also.

Selecting villages using a typology approach

The socio-economic component identified six broad agro-economic zones within the project's operational area; these formed the basis of a more detailed household typology. The location of these zones follows a west-east transect in Savannakhet province in southern Laos, from the lowlands adjacent to the Mekong River, to the uplands adjoining the Vietnamese border. The defined zones include irrigated lowland, supplementary irrigated lowland, rainfed lowland, transitional (households engage in both lowland and upland activities), diversified upland and remote upland. FV were selected to represent these major types of agro-ecological zones. Taking a typology approach to planning and applying technologies is an identified method for outscaling results, allowing a clear definition of the application domain for the knowledge generated and integrated farming systems that may be possible within each typology.

Activity implementation

The project worked in the FV for the life of the project, and for three seasons as targeted areas for integrated activities (2012 – 2013) (Table 1). The development of activities over the seasons shows a clear move from individual component activities towards more integrated activities for research and demonstration. There was a limit to the activities that could be undertaken in the first season, but several additional activities were identified in each village where the project could 'value add' onto previous component activities. In the first season, the project worked with 26 farmers in six villages, primarily on Best Management Practices for lowland rice, forage systems for improved animal production and submergence tolerant rice demonstration.

In the dry season of 2013, the post-rice crop trials were the first real opportunity to apply an integrated planning process in the target villages. In suitable locations where supplementary irrigation was available, the post-rice sweetcorn crop was included as an integration point, with input from all components for improved sweetcorn production. Management recommendations for sweetcorn were adjusted (staggered planting times, irrigation rates) to allow this activity to provide a livestock feed source over a longer period; this may also have implications for marketing options. The need to develop protocols in conjunction with each other was agreed, to ensure synergy for what was delivered to project district and farmer collaborators. In the wet season of 2013, activities were maintained both for integration and for use as sites for farmer learning. In addition to existing component activities within the FV sites, district staff developed District Action Plans to extend promising technologies within their districts. These included demonstration sites, cross-site visits and farmer training sessions for relevant technologies. These plans enabled the district staff to have more input into the setting of priorities and activities for extension activities within the project.

All learning and interaction with stakeholders takes place within local institutional and political contexts, which were reflected in FV settings; real learning hinges on context sensitivity, tactical flexibility and collective engagement in problem solving (Castella et al., 2006). These sites allowed a learning exchange between district and provincial agriculture staff, farmers and researchers, as the synergies in these systems became better understood and adapted to niche situations, resulting in some of the research activities being adapted based on joint feedback from farmers and researchers. For example, farmers in one village (Ban Phanomxai) expressed a need for options to manage a major insect pest of wet season rice, Rice Gall Midge. Farmers reported regularly losing over 40% of crop yield due to this pest. Several different management options were trialled in order to complement the existing work being done on rice production (variety selection, nutrient management, Best Management Practice implementation) (Table 1). Common sites lead to improvements across the farming system, as farmers could observe several new technologies in a similar environment. This situation allowed farmers to gain experience and confidence in the application of new technologies under local conditions.

Table 1. Activities implemented in Focal Village sites in 2012 - 2013

Village	Activities implemented		
	Wet Season 2012	**Dry Season 2013**	**Wet Season 2013**
Lowland A (Supplementary irrigation)			
Ban Nagaxo, Outomphone	– Direct seeding - rice – Site-specific nutrient management – Forage – Poultry management – Best Management Practice - rice	– Staggered planting of sweetcorn, improved management, irrigation interval trial, feed stover to livestock	– Direct seeding rice demonstration (DAP) – Rice variety demonstration (four most suitable varieties) – Rice with fertilizer after sweet corn
Ban Phanomxai, Phalanxai	– Best Management Practice - rice – Forage production – Rice variety trials – Site-specific nutrient management of rice – Monitor Rice Gall Midge damage/yield relationship	– Staggered planting of sweetcorn, improved management, irrigation interval trial, feed stover to livestock – Rice Gall Midge pheromone trial	– Best Management Practice for rice demonstration (DAP) – Rice variety demonstration (four most suitable varieties) – Rice Gall Midge ecological engineering trial – Variety trial for Rice Gall Midge resistance – Rice Gall Midge pheromone trial – Forage production demonstration (DAP) – Rice with fertilizer after sweet corn
Ban Nahsomvang, Phontong		– Staggered planting of sweetcorn, improved management, irrigation interval trial, feed stover to livestock	– Rice with fertilizer after sweet corn
Lowland B (Rainfed/Supplementary irrigation)			
Ban Done Jod, Phontong	– Forage production – Poultry management – Best Management Practice - rice	– Irrigated forage production – Staggered planting of sweetcorn, improved management, irrigation interval trial, feed stover to livestock – Intercropping peanut - mungbean	– Rice with fertilizer after sweet corn – Forage production and use – Nutrient cycling trial (cattle/forage) – Pond lining trial
Transitional			
Ban Napokham, Phin	– Forage production – Best Management Practice - rice	– Forage production	– Forage production and use – Nutrient cycling trial (cattle/forage) – Rice with fertilizer after sweet corn – Rice variety demonstration (four most suitable varieties)
Upland			
Ban Nong vilay, Nong		– Staggered planting of sweetcorn, improved management, irrigation interval trial, feed stover to livestock	Rice with fertilizer after sweet corn

Integrating project activities

For research projects, taking an integrated approach to the application of improved technologies can help facilitate farmer-extension-researcher interaction (Castella et al., 2006). Focusing on integration of project knowledge of technologies at the farm level, applied in a way that fit the Lao smallholder farming systems context, aimed to benefit farm households and communities. The aim was to introduce improved options for different parts of the existing farming system in a way that fit with the local conditions, and through this explore the effects of systems changes. A better understanding of the integration points and the whole farm system could test the ability of relatively small changes to the existing systems to bring about positive change within the farming system.

FV sites were valuable as an integrating factor for project activities, offering targeted sites for practical on-ground implementation of activities. They provided a common location to work together, enhancing organisational integration. By selecting these common sites, opportunities for dialogue and cooperation among project components were enhanced. For researchers, the use of FV also allowed a space to see the whole picture, giving insights into how events are interconnected, which can lead to targeted interventions for change. Using a FV approach meant that project components worked together more closely, and took a more problem-oriented approach, rather than strictly disciplinary. This was seen in terms of project planning meetings, project field visits that included members from all components (as opposed to strictly component visits), and the

development of protocols which incorporated different activities. Incorporating the FV sites into the project structure highlighted the importance of establishing good communication and working relationships among project counterparts. It is acknowledged that provincial and district staff are an important source of support for farmers; however, the process of different disciplines from these organisations working together at a common site or on an integrated activity is new, and required an adjustment in the way of thinking. Ongoing support is needed for this to happen, including training, mentoring, planning and budget allocations. There is a need to not only build technical skills, but also to improve competency in fundamental skills such as facilitation, stakeholder engagement, monitoring and evaluation and impact assessment at all levels (Gonsalves et al., 2005; Kristjansen et al., 2009). The development of such skills was a key focus of the knowledge sharing approach, and was reported by district staff, who rated stronger networks and improved communication as outcomes associated with the project (see Sengxua et al, this issue).

One of the risks of systems research approaches such as described here, is that it often takes a long time to see changes in a system. It is recognised that the level of integration at any site is an evolving process, and that the benefits from integration and systems research take time to accrue (Tipraqsa et al., 2007), meaning that there may be limited additional outputs from the first few seasons. In locations like rural Laos, where many other management factors influence the farming system, and detailed record keeping and site data are often limited, this type of research can be challenging to undertake. Nonetheless, it is important that such research is undertaken to allow the identification of the wider effects of individual activities within the farming system, and increased understanding of the interplay between constraints and solutions, and the prioritization of these. In using the FV approach at the local level, these locations became areas of learning exchange and ownership that in some cases were maintained after the project concluded, with farmers and local staff as experts able to share their knowledge and experiences.

Conclusion

FV sites had value as an integrating factor for the project activities of the research project. They provided local relevance and practical application to enhance understanding and adoption of technologies introduced. FV sites were used for learning sites for project participants to see the effects of integrated activities while offering pathways for outscaling promising technologies. At the FV sites the project targeted proactive farmers in progressive villages as a way of promoting uptake of agricultural activities with high potential. Importantly, they provided a common location to work together, enhancing organisational integration. By selecting these common sites, opportunities for dialogue and cooperation among project components were enhanced.

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Capacity building and external linkages assist use and integration of technology options for research and development projects

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Abstract
Effective research and development strategies rely on satisfactory capacity within all levels of the agricultural sector. One common avenue for local staff to access capacity building opportunities is through engagement with research and development projects. The project described in this paper supported capacity building for extension staff and farmers, through the implementation of on-farm research and by providing training and learning opportunities in key areas identified by the project and by local stakeholders. A skills-based needs assessment was undertaken to determine training requirements. Priorities for district staff were based on data analysis and reporting, project management and computer skills. For farmers, the needs were more technically based, mainly incorporated into cross-site visits for learning and knowledge exchange. The project provided over 450 training places, including participants from private companies, regional universities and other local projects. Likewise, 500 people participated in cross-site visits over a broad range of topics and locations. Enhanced capacity, and familiarity with what others had tried, assisted the teams to implement their technologies in several focal villages. A survey of project staff generated feedback on project activities and the resulting changes to staff and farmer's skill development and experiences. Semi-structured interviews were conducted with key informants in the project leadership, district staff and farmers. Major benefits noted by both farmers and district staff were increasing knowledge and improving farm productivity. Additionally, the project engaged with a wide range of external stakeholders, including research and development projects, private companies, NGOs and Educational Providers in southern Laos.

Keywords
Implementation; extension; research; agricultural development; competencies

Introduction

Agricultural research and development are fundamental platforms on which rural communities rely in order to improve food security, reduce poverty and sustain economic development (Beye, 2002). Effective research and development strategies rely on adequate capacity within all levels of the agricultural sector, including individuals, public and private organizations, and research, extension and educational institutions. In many developing countries, this capacity is often lacking. For this reason, capacity building is often a key component of research and development projects, whether it is an explicit objective or not (Posthumus et al., 2012). While it is a desirable outcome in its own right, it is also often necessary in order to be able to achieve planned project activities. Capacity is a multi-faceted concept that incorporates a range of competencies (Fowler and Ubels, 2010); in an agricultural research and development setting, individual capacity incorporates technical knowledge, basic research skills and extension approaches, as well as 'soft skills' such as communication and facilitation (Ifenkwe, 2012; Okorley et al., 2009). As approaches to agricultural research and development become more multi-disciplinary, multi-organisational and multi-stakeholder, there is a noticeable focus on these soft skills that are becoming increasingly important (Posthumus et al., 2012).

An integrated research project on 'Developing improved farming and marketing systems in rainfed regions of southern Lao PDR' (hereafter referred to as 'the project'), funded by the Australian Centre for International Agricultural Research (ACIAR), was implemented in southern Laos from 2010 – 2014. The project was set up as a partnership between the National Agriculture and Forestry Research Institute (NAFRI) (the in-country project lead) and several international research organizations, and linked with provincial and district agriculture staff for implementation of on-farm research in eight districts. Capacity building was an explicit goal of this multi-disciplinary project from the outset, which worked across the farming system in crop agronomy, livestock, water and hydrology and socio-economics and marketing.

At the commencement of the project, knowledge sharing activities focussed on delivery from individual components, rather than the whole. With recruitment of additional Lao-based staff, the focus broadened to build on the technical training program, orienting more towards trying to build skills in integrating, reporting and outscaling project activities (see Bouahom et al, this issue). In addition, priorities were identified for the production and dissemination of information, and stakeholder linkages identified and established.

Avenues for capacity building

Involvement with research and development projects is a common avenue for capacity development of local staff (Photakoun, 2010). Staff working with the project were provided with formal learning and training activities (workshops, training sessions, study tours, cross-site visits), as well as ongoing informal mentoring and on-the-job training opportunities through interaction with and implementation of on-farm research sites.

Training and study visits

In total, the project provided over 450 training places (targeting a consistent group of provincial and district staff and farmers). Initially, training within the project was predominantly focused on developing staff technical skills to allow them to fulfil requirements for project activities. A skills needs assessment was undertaken to determine training requirements for farmers and district staff, to ensure that sessions developed were relevant and useful for all parties. Priorities for district staff were based on data analysis and reporting, project management and computer skills, with some technical requirements also. For farmers, skills needed were technically based, and were mostly incorporated into cross-site visits to relevant areas for learning and knowledge exchange. The training sessions were designed to build on each other, and to make use of previously acquired knowledge. They reflect the needs of the project, starting with a focus on technical topics, and subsequently orienting more towards trying to build skills in integrating and reporting on project activities. The aim of these training sessions was to start to draw together the various technical skills that had been built, with some more 'fundamental' professional skills, to allow these technical skills to be outscaled. Fundamental professional skills included topics such as research design and methodologies, data analysis, documentation and presentation skills, computer skills, and case study writing.

Specific technical needs were addressed by study visits; for example, 16 farmers visited northern Laos to gain an understanding of forage and livestock systems, as experience was limited in the south. Eight district staff visited Thailand to become familiar with livestock production and research facilities there. Researchers also visited Cambodia to see progress in direct seeding, mechanisation and water management. In total, over 500 cross-site visit places were provided for knowledge exchange. These cross-site visits covered a broad range of topics, which reflected interest from farmers and provincial and district staff, as well as successful project trials and demonstrations.

On-farm research

Participants highlighted the value of training and study visits undertaken in conjunction with the on-farm research approach implemented by the project; this was seen as successfully incorporating formal training with hands-on experience. In a survey of farmers who participated in project activities, 75% indicated that practical and applied learning through on-farm research was one of the best learning methods for them. The consistency in the responses was such that 50% of farmers surveyed stated verbatim "het/long tua jing" (do/try the real thing), and two farmers talked about "bung/hin tua jing" (watch/see the real thing), using the same words to express their preferred learning style. This pragmatic approach is reflected in many farmers' comments, for example that on-farm research is *"relevant to our daily lives and concerns"*.

Stakeholder linkages

External links are important for outscaling and for building local capacity. It was important to be flexible in terms of who the project linked with and how, given that there were different agencies working in each province, and they had different needs and capacities. Broadly, the links established were through two-way training and learning (research and development projects and funding bodies, private companies, non-governmental organisations), and engagement with educational providers to provide learning experiences for students, who also aided the project with research implementation and data collection (universities and agricultural colleges). An agri-network was also established in one province to link with projects working on similar issues and in the same locations, for sharing information and understanding operational challenges.

Capacity building benefits and outcomes

Links between cause and attribution can be hard to define for capacity building approaches (Posthumus et al., 2012), but in this case the project process provides a background for this. A survey of project staff was conducted to generate feedback on project activities and triangulate responses in changes to staff and farmer's skill development and experiences. Semi-structured interviews were conducted with key informants in the project leadership, district staff and farmers. There was substantial skill acquisition and improvement by district staff over the course of the project and increases in overall working capacity, despite the relatively short timeframe under consideration (2010 – 2013). Major benefits noted by both farmers and district staff were increasing knowledge and improving farm productivity. Additionally, district staff noted that the on-farm research was beneficial for increasing links and building rapport with farmers.

These identified increases in capacity ranged across both technical skills such as subject matter competency, research, and extension, as well as personal skills such as communication, confidence, and critical thinking. Based on the skills self-reported during interviews with district staff, technical subject matter competencies in either crop or livestock areas were most frequently mentioned, according to the specialization of the staff member's field of work. Technical research skills were overall the most frequently mentioned improved skill as they span across both crop and livestock specialists. Despite limited (or no) research experience prior to the project, in many districts local staff became capable of implementing research protocols with minimal oversight. In some cases it was observed that understanding of the research process had reached the level where staff could communicate research objectives and methodologies to others. Staff could take complex information and transfer it in a manner that allowed farmers with very limited education to understand.

In reviewing the project management assessments of district staff performance across the eight districts, communication and attitude emerged as two key concepts critical to working success. It is interesting to note that technical skills, while important, did not factor most prominently here. Communication, particularly with farmers, is one of the skills that most distinguished the most effective districts from the others; 75% of district staff interviewed ranked their own skills in "communicating new information to farmers" at least 1 point higher after the project compared to before, on a 5-point scale (range 0-5). One participant reported an increase from 2 to 4.5 in the "communicating with farmers" category, showing marked improvement during the project despite having 11 years experience already working in the district. This district staff noted that, *"Even after working all these years I didn't have a strong extension method."*. Notably, this district was also rated most highly by project leadership in terms of increased capacity, and project activities here were very successful, including implementing forage based feeding systems, improved rice varieties and dry season cropping. Similarly, improvements in extension capacity became much more prominent when respondents were asked to describe changes in their work since the project: *"I had nothing to talk [about] when I met famers before working with the project. Now I know how to get information ... and give them recommendations"*. Communicating research problems to farmers in the local context, and being able to explain both the experimental procedures and the potential benefits of the results helps to generate farmer interest in participating with the project and also facilitates better collaboration.

Attitude was also frequently cited as improved both in district staff self-assessments and in project leadership responses. Attitude in this case includes motivation, cooperation, willingness to learn, and confidence. Motivation has been previously recognized as playing a critical role in improved capacity (Ifenkwe, 2012; Okorley et al., 2009). As one project leader said, *"Capacity building is also about getting people enthused about a subject – in a lot of cases, we've been successful in this"*. Farmers also reported positive changes in district staff attitude, for example stating *"District staff are better than before; it is good because they are interested"*. Most district staff noted improved attitude and increased confidence over the duration of the project; personal characteristics and attitude have been identified as key factors that can enhance or constrain capacity building efforts (Posthumus et al., 2012). This self-assurance coupled with technical subject matter competency helped farmers have more confidence in the capacity of extension staff as well. Farmers reported this increase in staff capacity, saying that *"DAFO are really different than before, better than before. They have more specific and relevant information to suggest"*.

In addition to increases in a wide range of technical, research and interpersonal skills, there were also numerous positive examples of increases in working capacity among the district staff during the course of the project. Positive changes were reflected in the district staff self-assessments, in the project leader assessments, and in the comments from farmers. Farmer feedback on the working capacity of district staff over the course of the project confirms that staff are more active (56%) and knowledgeable (50%), reflecting

farmer comments that district staff now have more technical knowledge to share and have better relationships where they are more engaged with farmers that before.

Farmers

Nearly all farmers interviewed (15/16) noted technical skill improvement in the various areas of research conducted on their farms, generally focusing in either crop or livestock production depending on the specific research activities. Four farmers reported increases in both crop and livestock technical skills where multiple research activities were undertaken with a single household. This is a positive outcome reflecting effective extension from the research activities, where previously farmers in many cases were working from very traditional, no- or low-input systems with limited technical management or intervention. In addition to the technical agricultural knowledge and skills, farmers also noted a gain in many interpersonal skills such as communication, attitude and technical confidence.

As a result of this capacity improvement, farmers reported a number of changes to their farming practices following the commencement of the project. Many of the responses indicated changes to rice production systems, other crop production systems, and livestock systems; frequently farmers also noted that their overall productivity and livelihoods were increased as well. Referring to the benefits of an on-farm trial with forage production and cut and carry livestock feeding, some of the changes reported by farmers are quite dramatic, including 2- to 4-fold increases in income; "*Now we get bigger cattle, higher prices. In the past I only got 7-800,000 kip, but now I can sell for 2,000,000 kip at the same age cattle."* Other benefits included fewer losses and better health of animals as a result: *"Last year I lost 7 cattle. But this year the cattle come on their own and we have no loss...the cattle have enough to eat and aren't dying. They are still free-ranging but they stay nearby."* Higher farm productivity directly improved farmer livelihoods as well, as seen in one family's comments on changes in their farming systems, *"before the event rice production was our normal work but rice was not enough for consumption. Now, we can sell rice".*

Conclusion

The project developed a portfolio of activities in order to build capacity and promote application of technical outputs. Significant effort was devoted to capacity building activities for provincial and district staff, and to providing opportunities for farmers to experience and discuss technologies they were interested in exploring further. Additionally, the project team made links with institutions in the provinces for capacity building and outscaling purposes. As a research project, enhanced capacity meant achieving better research results; but from a general capacity building perspective, the ultimate aim was to help people and organisations perform their roles more effectively. Capacity building outcomes included improved technical, research and interpersonal skills, which then lead to improved extension capacity and more effective working approaches for district staff. By improving research skills, district and provincial staff were better able to do their job and were more motivated; this was reported by project management, staff themselves and the farmers they engaged with. District staff also reported having stronger networks and improved communication, both with farming communities and their institutional colleagues. These improvements led to noticeable impacts for delivery of services to their farming communities, who were then able to practically integrate new technologies into their farming systems.

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Taking stock of agronomy research in Australia – a bibliometric analysis

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Abstract
A study by ACDA has shown that publications from Australian agronomists have been consistent in number over the 18 years analysed. The global share is trending downwards but this is balanced by increases in citations. There is a strong presence in the top cohorts of papers as measured by citations. Universities have substantially increased their share of publication output mainly at the expense of the government sector. These findings provide insight for the agronomy research community and research funders on the outputs by research providers and establish a platform for future research investment.

Key words
Agronomy publications, citation rates, ACDA

Introduction

Much has been written about agricultural research and development in agriculture including the reduction in funding globally (Pardy *et al*. 2013) and the decline in research intensity in Australia (Mullen 2007). There has also been a significant shortfall in enrolments in agricultural undergraduate degrees in Australian universities (Pratley 2012; Pratley and Acuna 2015) with acute shortages in areas of agronomy. There are flow-on effects to low numbers in research higher degrees accentuated by the outdated conditions for postgraduates and early career researchers (Pratley 2013). We have seen declines in state agency research and extension activity over a long period and prospects for that to be reversed are slim at best. Retirement of leading academic and consultant agronomists raises questions about the levels of performance of agronomic research in Australia and the prospects of future work. This paper considers aspects of long-term trends in output and relative performance in Australian agronomy as measured by publications in the Scopus database. These comprise peer reviewed journal articles, conference papers and books.

Methods

The Australian Council of Deans of Agriculture (ACDA) commissioned a bibliometric study of agricultural research from Australia and this paper reports aspects that relate to total global publications related to agronomy, undertaken by Science-Metrix, based in Canada. *Number of papers* was obtained using full-counting, i.e. each paper is counted once for each entity (e.g., country, organisations) listed. For example, a paper authored by two researchers from the University of Melbourne, one from the University of Sydney and one from the University of Toronto, is counted once only for the University of Melbourne, once for the University of Sydney, once for the University of Toronto, once for Australia and once for Canada. *Number of citations* is obtained using full-counting. Citations were counted for two subsequent years following the year of publication, i.e. citations were counted for 2005–2007 for a 2005 publication, as this results in the same citation window for all years and allows comparison of yearly citation trends. The global data were described as 'Agronomy and Agriculture' through Scopus and approximated to the Fields of Research (FoR) codes 701, 703 and 503 (agriculture and farm management, crop and pasture production, and soil science respectively).

Results and discussion

The numbers of papers published for the period 1996 to 2013 in agronomy and related areas are shown in Figure 1. Output has been steady for that period being around 500 per year with a peak output in 2005-2007 at around 600 annually. However when it is compared with production levels globally (Figure 2) it can be seen that Australia's contribution has declined from a high of above 7% in the first few years to just above 3% in the period 2009 to 2013. This is clearly a substantial reduction in relative contribution to world knowledge in this area.

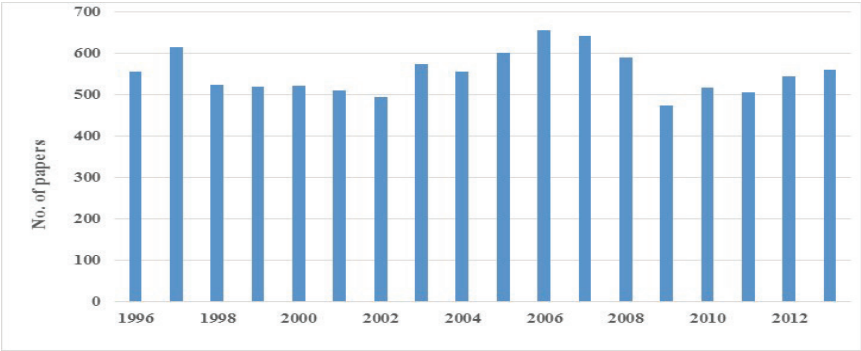

Figure 1. Number or papers published annually by Australian authors in agronomy and related areas for the period 1996-2013 (ACDA, 2015 unpublished)

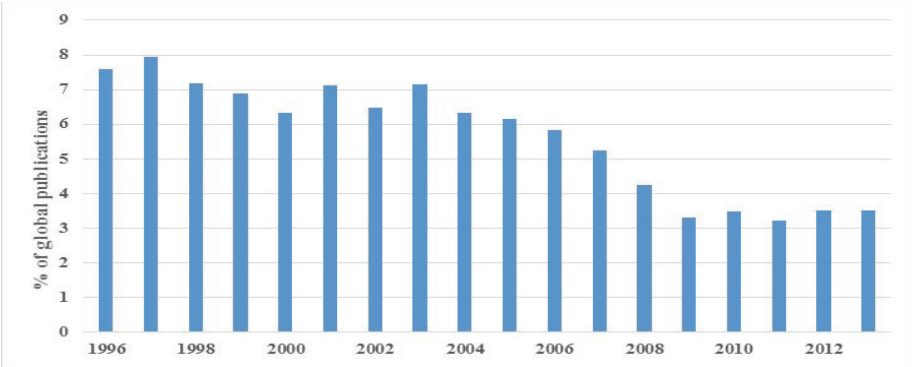

Figure 2. Proportion of global papers published annually by Australian authors in agronomy and related areas for the period 1996-2013 (ACDA 2015, unpublished)

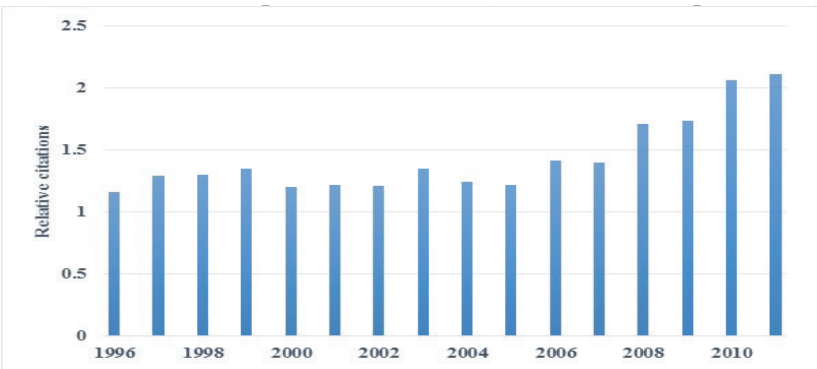

Figure 3 Relative global citations of Australian agronomy publications for the period 1996-2011 (ACDA 2015, unpublished)

In contrast however analysis of citations of Australian agronomy publications shows that our agronomy is well regarded internationally being always above 1.0, the global average (Figure 3). From about 2006 onwards the relative citation index has increased, being in excess of 2.0 in the last two years of measurement. This would appear to be a positive trend but may also reflect greater electronic access to Australian papers, the lack of a parochial journal with the CSIRO journals taking an international position, or academics chasing higher impact factor journals through the influence of the ERA process (Excellence in Research in Australia).

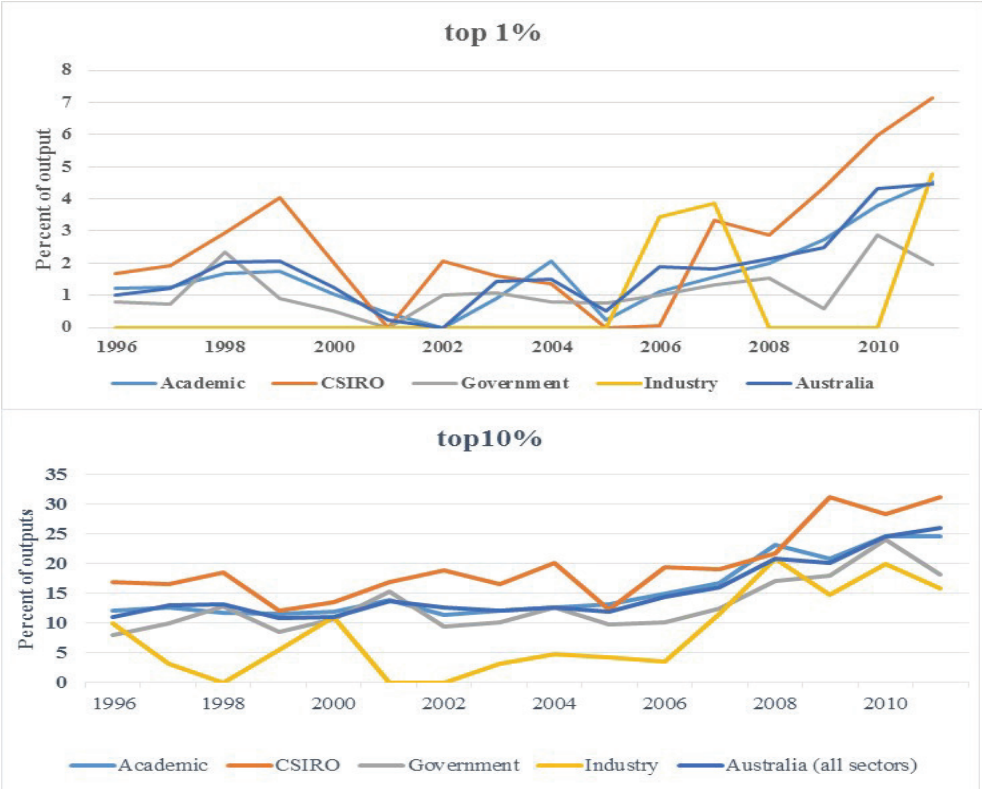

Figure 4. Relative global performance of Australian agronomy and related publications as measured by citations for the period 1996 to 2011; a. in the top 1% (top) and b. in the top 10% (bottom) (ACDA, 2015 unpublished)

Further analysis of the quality and potential impact is the proportion of papers in the top global cohorts. In the top 1% of cited papers (Figure 4a), Australian agronomy has performed at better than the world average in most years with CSIRO regularly being well above the average, 6 to 7-fold in the last two years of the study. There is a noticeable upward trend for Australia in the top 1% in the most recent 5 year period. In the top 10% of papers cited (Figure 4b), there is a clear above average performance with a strong upward performance in the last 5 years of the study period with about one quarter of the papers in the top 10% being those recorded as Australian. CSIRO leads the way but all main sectors a well represented in recent years at that high performance level. This does suggest that agronomy research in Australia is having a strong impact on agronomy research more widely.

In terms of the generators of output in Australia, Figure 5 shows publications for the three major sectors CSIRO, universities and government. There is a very strong upward trend from the university sector over the period and a noticeable decline in output from the government sector. These trends may be a partial reflection of the movement of research activity from state governments to universities as has happened in Tasmania and Queensland for example. It also reflects the focus in universities on the ERA process and the need to be stricter on Field of Research coding of projects. CSIRO has also experienced a steady but modest decline in number of publications across the period of study.

Within the university sector there are many contributors. Figure 6 shows the top 20 universities with respect to agronomy publications with the period split to observe the changes in output with time. The University of Western Australian is the standout performer with over 700 papers in the last 9 years. There are 7 universities with over 200 publications over the last period. The data show that most universities increased performance from the early to late period with Charles Sturt University in absolute terms being the major improver.

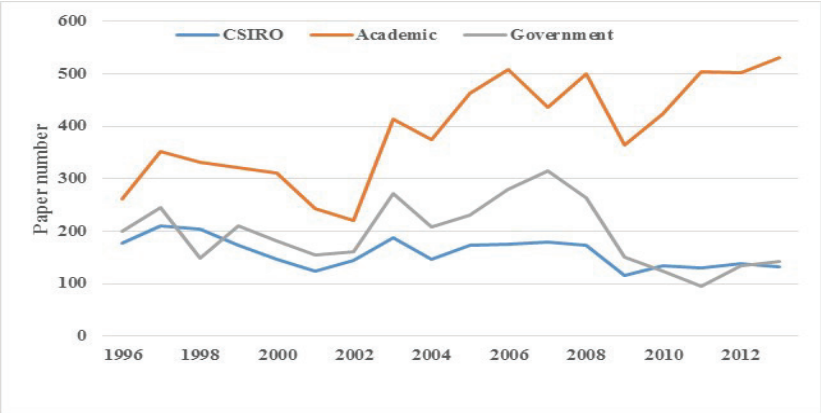

Figure 5. Numbers of publications from CSIRO, universities and government in Australia over the period 1996-2013 (ACDA, 2015 unpublished)

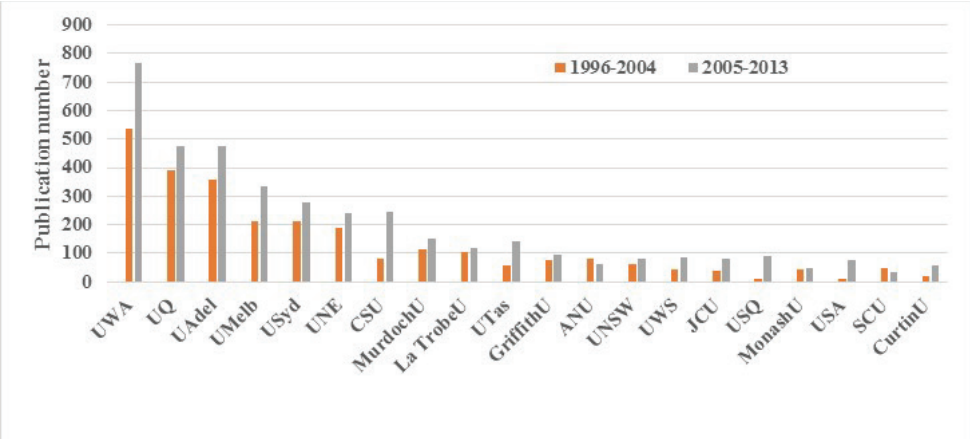

Figure 6. Publication numbers in agronomy and related areas for 20 universities for the periods 1996-2004 and 2005-2013 (ACDA 2015, unpublished)

Conclusions

Australia has performed consistently in the global agronomy publication arena and there is strong evidence that its output is of high quality based on its relatively high citation rates and continually strong, presence in the top echelon of papers. Of concern is the downward trend in relative output over recent years and the loss of 'market share' globally. This is somewhat balanced by the increased citation rates received by Australian papers. There has been a marked increase in Australian publications in the second half of the period and the relative outputs between sectors has changed with universities assuming a greater proportion at the expense of government agencies, a trend likely to continue. Overall agronomists can be pleased that their work is so well received internationally.

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Constraints to greater use of pulses and forage legumes on acid soils of the high rainfall zone of south-eastern Australia - focus groups and a farmer survey

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Key words
Pasture phase, waterlogging, faba bean, sustainability

Abstract
Reliability of legume rotation options on low pH soils of the high rainfall zone (HRZ) of south-eastern Australia needs improvement. This report summarises results from the consultation phase of a project that aims to provide farmers and advisors with information to improve the "performance" of legume species under local environments and improve understanding of rotational benefits these species can provide to the farming system. Data collected from a farmer survey, focus meetings and interviews were used to describe the current role of pulses and legume forage crops and pastures in farming systems, to identify factors limiting their adoption in the HRZ and to guide research priorities. Results revealed 77% of surveyed farmers sow legume species on part of their main cropping area annually. Of these 65% sow pulse crops for grain, 11% grow these species as 'manure' crops, 37% sow legumes for hay or silage and 74% sow a legume-based pasture for grazing. The process identified opportunities to expand legume use through improved technology, including strategies to avoid weed seed bank build up; tolerance to the HRZ environment; nodulation of legume species, including adaptation of rhizobia strains; disease resistance of pulses; understanding of the role for micro-nutrients; and optimisation of yield and nitrogen fixation and guidelines for more accurate nitrogen budgeting. Quantification of the benefits of legume species to the farming system is needed. Agronomic, financial and climatic factors should be considered along with a comparison of crop sequence options, particularly those incorporating legume species into the dominant cereal/canola system.

Introduction
Extensive agricultural production in the high rainfall zone (HRZ) is dominated by mixed farming systems. Ewing and Flugge (2004) reported a shift from livestock dominant systems and the development of "a more diversified production system based around an increased proportion of cropping", driven by innovation and economic signals. MacEwan et al (2010) reported further expansion of cropping in the HRZ of south-eastern Australia in response to economic and climatic drivers.

Cropping area in the HRZ has expanded significantly since the early 1990s, particularly in southern Victoria where, for example, from 1995 to 2010 the area sown to grain crops increased 600% in the Ararat and Golden Fields Local Government Area of south-western Victoria (SW VIC) (Burns 2015). However, HRZ cropping systems are dominated by cereals and canola. Riffkin and Thrall (2013) considered that lack of diversity and reliance on fertiliser nitrogen (N) is likely to negatively impact on the long-term economic and environmental sustainability of current broadacre cropping systems of the HRZ.

There is a need for profitable legume rotation options on low pH soils of the HRZ, but research, development and extension (RD&E) investment has focused on the medium and lower rainfall zones. A Grains Research and Development Corporation (GRDC) funded project is supporting investigations by NSW Department of Primary Industries (DPI) into the role of legume crops and pastures in building the resilience of HRZ cropping systems, specifically through reduced reliance on fertiliser N; improved management of herbicide resistance; and improved integration of pastures and forage crops in cropping systems.

The preliminary phase of this project involved consultation with famers and other stakeholders to: (i) benchmark the current use and role of legume species in cropping systems; (ii) assist in identifying factors limiting adoption of legume crops and pastures and implementation of effective crop sequence management in the HRZ; and (iii) identify research priorities.

Methods
The regions targeted for the GRDC project were those with a long-term average annual rainfall of above 550-600 mm in southern NSW and north-east Victoria (VIC), and above 450-500 mm in the south-east of South

Australia (SA)-VIC Border, SW VIC and Gippsland regions and in Tasmania (TAS). Regions of altitude above approximately 500 m and those with topsoils of pH above 6.0 ($CaCl_2$) in were not included in the study.

Baseline data gathered from farmers, private and public sector advisors, consultants and technical specialists were used to describe the current role of legume crops and pastures in farming systems on the acid soils of the HRZ of south-eastern Australia. The approach involved three activities: (i) farmer survey; (ii) focus meetings; and (iii) interviews with farmers, advisors, consultants, technical specialists and researchers.

Survey

In 2014 farmers from the target area were invited to complete 10 survey questions that were developed and delivered using SurveyMonkey®, an online survey platform. Farmers provided details on location, farm size, crop and livestock enterprise mix, cropping area, cropping sequence on the main cropping soils and legume species used. They were also asked to consider and rate (i) factors that may influence their decision to include legume crops and/or pastures in crop sequences and (ii) areas in which they require more information or technology to increase their confidence to use legume species. The listed options were rated as either 'Not at all important' (with a rating of 1), 'Not important', 'Somewhat important', 'Important' or 'Very important' (with a rating of 5). The results were then analysed to provide a rating average and ranking.

The analysis of the 221 usable survey responses provides baseline data on adoption of legume crops and pastures in cropping systems, the factors affecting crop sequence decisions, and provides an indication of the information and technology gaps that need to be addressed in order to improve adoption of these species.

Focus meetings

A series of 5 focus meetings were conducted in 2014: 2 in VIC and 1 each in NSW, SA and TAS. The 52 attendees included 35 farmers and 17 agribusiness representatives or advisors. The facilitated discussion provided an overview of the diverse cropping systems of the HRZ, farmer understanding of legume agronomy, including regional variation, and detail on factors limiting legume performance and adoption.

Interviews

Individual interviews with 40 farmers (who had also filled out the survey), advisors, researchers and technical specialists from the study area provided context and detail of the issues identified through the survey and meetings, as well as factors not raised but potentially impacting on legume performance. These also provided an insight into the farming systems and practices of the broader population of farmers not represented in the survey and focus meetings.

Results and discussion

The 221 farmers responding to the survey manage in the order of 488,000 hectares, of which approximately 282,000 hectares is cropped annually. Average farm size is 2,166 hectares (excluding outliers), with an average of 1,323 hectares (61%) cropped annually. Most respondents (86%) operate mixed farming systems, with the other 14% describing their system as 'intensive cropping' (i.e. no livestock enterprise).

Individuals interviewed for this study suggest that these results over-estimate the significance of cropping in the HRZ, particularly in the SW VIC, SA and TAS regions and reflect the cropping bias of the sample of farmers participating in the survey. However, advisors report continued expansion of the cropping area in SW VIC. This is opposite to the apparent trend in the NSW Slopes and SA-VIC Border regions, where crop area has reportedly stabilised or even declined in response to unpredictable cropping seasons, a buoyant lamb market, and reliability of return and perceived lower risk associated with sheep versus crop enterprises.

The current role of legume species in farming systems

From the survey results 77% of farmers annually sow legume crop and/or pasture species on their main cropping areas. Of these farmers: 65% sow and harvest pulse crops for grain, 11% sow legume species as brown or green manure crops, 37% sow legume species for hay or silage production, and 74% sow pasture legume species for grazing.

Since the early 1990s canola has replaced lupin as the break crop of choice on the better drained soils across most regions of the HRZ. While *L. angustifolius* is grown across all regions, L. albus plantings are confined to well-drained soils of the Slopes of NSW. The study indicates that lupin is considered a low maintenance,

low input crop that can be "sown and forgotten". It is the dominant pulse in the NSW-VIC Slopes region where many farmers are sowing lupin crops without fertiliser.

Faba bean is the pulse crop best adapted to soils prone to waterlogging and is the pulse of choice in the SA, SW VIC and Gippsland regions. Despite having a relatively high management requirement, the area sown to faba bean is predicted to increase as farmers (and advisors) gain confidence and experience. Prompted by reports of high yields and grain prices, and lack of advisor experience, farmers are undertaking their "own research" on faba beans, trialling small areas (30-100 ha) to develop experience and confidence.

The study suggests that legume species are rarely sown as brown or green manure crops on the high-value farming country of the HRZ. Most farmers are reluctant to forego a year of income and therefore 'manuring' is likely to be a last resort option when there is an unexpected 'blow-out' of herbicide resistant weed populations, most commonly annual ryegrass (*Lolium rigidum*). A hay or silage cut, which provides a potential income source, is the preferred practice to prevent weed seed set. Manure crops are often low input and sown with minimal fertiliser or weed management, which is likely to compromise legume dry matter production and N fixation.

Poor quality of pastures, dominated by naturalised annual species is a concern of VIC, SA and TAS advisors interviewed for this study. Reported sub-optimal performance of pasture legumes was attributed to low priority of the livestock enterprise leading to minimal investment in fertiliser and pasture improvement, poor species and/or variety selection and poor understanding by some farmers and advisors of basic pasture management principles. Advisors noted that many farmers see the pasture phase as a "fix-all" and opportunity to start the cropping phase "with a clean slate". However, weed management, legume content and growth in these pastures is often poor and N fixation is likely to be very low.

Factors affecting crop sequence decisions

In order to gauge the factors that may influence the decision to include legume crops and pastures in crop sequences, the survey asked farmers to rate the relative importance of a number of listed factors, from 'Not at all important' (with a rating of 1) to 'Very important' (with a rating of 5). The results were analysed to provide the ranking and rating averages shown in Table 1. Farmers were also asked to rate the relative importance of areas of information and technologies, which they require to increase their confidence in using legume species in crop sequences (Table 2).

Table 1. The ranking and average rating of factors that influence farmers' decision to include legume crops and pastures in their cropping sequence. The percentage of respondents who considered the factors presented as either 'Very important' or 'Important' is shown in parentheses.

Factors that may influence crop sequence decisions	Overall rank	Rating average
Increased weed management options	1 (89%)	4.3
Financial return of crop and system	2 (87%)	4.3
Disease management	3 (70%)	3.9
Diversity of income sources	4 (63%)	3.7
The cost of N fertiliser	5 (52%)	3.5
Ability to manage seasonal variability	6 (44%)	3.3
Pest management	6 (41%)	3.3
Logistics	8 (27%)	3.0

Responses from the survey and focus meetings indicate that weed management, estimates of break-even crop yield and simple gross margin calculations drive the crop sequence decisions of most farmers. It is apparent that the majority of farmers do not place an economic value on the additional rotational benefits of pulse crops such as N contribution or disease and weed management, and consider that every 'crop' must be profitable in its own right. As commented by a farmer at the SA focus meeting: "Farmers … often keep cropping as it is easy and delivers short-term financial gains (cash flow)".

The study results suggest that many farmers and advisors focus on the performance of cereals and canola and give limited consideration to the role of legumes in crop sequences beyond weed and disease management and production. However, the interview process identified industry knowledge gaps and indicated that key aspects of legume agronomy and management, which are likely to be compromising legume growth and

performance, are either unknown or are being overlooked. Application of known principles and development of new technologies has potential to improve performance of legume species through increased yield and N fixation. There is considerable information available that can be applied to the HRZ to improve legume performance through, for example, weed seed bank management, effective nodulation of legume species and legume nutrition (both macro and micro-nutrients). Further technical advances are needed in disease resistance and adaptation of legume crops and associated rhizobia strains to the HRZ environment.

Table 2. The ranking and rating average of areas of information and technology required to increase farmer confidence in the use of legumes in crop sequences. The percentage of respondents who considered the factors presented as either 'Very important' or 'Important' is shown in parentheses.

Information and technology gaps	Overall rank	Rating average
Weed management and herbicide options	1 (82%)	4.2
Legume crop and pasture options adapted to soil and climate	2 (81%)	4.1
Improved features of existing varieties e.g. disease resistance	3 (75%)	4.0
Quantification of financial benefits of legume crops & pastures	4 (72%)	4.0
Disease management	5 (68%)	3.9
Specific agronomy packages for legume species	6 (64%)	3.8
Stability of markets	7 (64%)	3.7
Improved inoculation (nodulation) of legume species	8 (54%)	3.6
Integrated pest management	9 (52%)	3.5
Trace element requirements of legumes	10 (48%)	3.4
Infrastructure and grain delivery options	11 (48%)	3.3

Conclusions

Although farmers across all HRZ regions are concerned about their over-reliance on canola, which they view as a high input, high risk crop, the lack of experience of most farmers and advisors in crops other than cereals and canola has limited the adoption of alternatives. The study suggests that dominance of the cereal/canola crop sequence and generational change has affected industry knowledge of agronomic principles essential for the performance of legume species in the HRZ.

There is potential to improve the performance of legume species on HRZ acid soils of south-eastern Australia. However, this requires concurrently building capacity of farmers and advisors to ensure effective adaptation of outputs from relevant RD&E investments in the medium and lower rainfall zones, and alkaline soils of the HRZ. Research aimed at improving disease resistance and adaptation of legume species to HRZ environments is also needed.

Most farmers aim to minimise the complexity of farming systems and the majority are unlikely to adopt unfamiliar technologies that increase the complexity of their system unless they have are provided with compelling evidence of the relative advantage of new practices or technologies and have access to experienced technical support. Financial studies comparing crop sequence options must provide long-term "whole of system" analyses that "separate the financial return for the crop and the system". There is a need to quantify the risk and consequences of crop sequence decisions, particularly with regard to management of herbicide resistance and disease.

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Smallholder farmer innovation. 2. Facilitating farmer agency through experimentation and learning about cropping systems.

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Abstract
Learning, and in particular generating new knowledge, appears to have played a role in transforming the lives of poor women farmers on the east India Plateau. Learning and knowledge generation seem to have increased their self-esteem and generated a desire to learn more as well as improving their physical well-being and position in society This paper describes our experience working with resource poor smallholder farmers on the East India Plateau to develop more diverse and intensive farming systems. Our focus is on developing the capacity of individuals for independent innovation rather than their skill in the application of specific agricultural technologies. Facilitating learning experiences through on-farm research on topics chosen by the community is central to our approach. Individual farmers learn from each other in self-help groups that provide a forum for farmer-scientist interaction. Locally developed vegetable cash crops and aerobic direct seeded rice are popular with farmers and adoption is expanding rapidly. Much of the local adaptation and dissemination is being driven by farmer-to-farmer communication and learning. Our experience confirms that despite often extreme poverty, malnutrition and discrimination these communities demonstrate high human capacity for innovation. Rather than a specific technology or cropping system, the real legacy of our approach is cognitive development in farmers, changing their perception of the environment in which they are working and enhancing their capacity for independent innovation in the face of increasing complexity and uncertainty.

Key words
Transformative learning, cognition, communication

Introduction

Many research projects working to improve the lives of small scale farmers start from the premise that poverty is a result of material disadvantage leading to economic disadvantage. From this assumption the obvious solution is to remove the material disadvantage, and on that basis agriculture projects tend to be centred on development and transfer of improved production practices that can assist to overcome material disadvantage. Such projects therefore focus on the potential impact of improved technology on crop production. But, when we put agriculture into a broader development context we realise we are working with a diverse complex situation and attempting to control the situation through a focus on one aspect is not appropriate. Therefore, from a development perspective we need to think about how to produce deep long lasting change to enhance people's lives; that change is not only in the technology they use but also in how they relate to their broader social, political, economic and physical environment. In doing so we acknowledge this is not a situation that we control but rather one in which we can facilitate a process that enables change to develop.

An alternative approach to development focuses on the development of the individual working to build capacity to not only change their practice but to work as innovators who can produce new approaches and practices that suit their needs and resources. One way to achieve this end is to take a learning approach. Learning is generally regarded as a good thing in the scientific and research communities. Learning is often mentioned but not so often described in the development literature (Ramsay, Bellotti, Narain and Kumar 2015). However, there are some issues with using learning as a focus. Firstly, learning is often associated with teaching with the expert teaching the novice. Secondly, when both groups are adults and experienced in life the relationship and association is different to the usual master pupil relationship. However, learning has a major advantage; it is something over which we as individuals can exercise control in comparison to, for example, the broader economic system over which individuals exercise virtually no control.

Learning, the theory behind it and the processes for learning are multiple and often contested (Blackmore, 2007). However, it is generally agreed that learning takes a variety of forms that can be described in a hierarchy (Ellström, 2001). Learning can for example, consist of factual knowledge, a conceptual framework to arrange that knowledge as well as the ability to notice patterns, generate and explain reasonable arguments and explanations and to draw analyses to other situations. An important element in learning is cognition. In this paper cognition is defined as the way in which one perceives, understands and makes use of the interactions between self and the environment to learn. That is, cognition provides the framework through which to make sense of experiences. Cognition can be considered a product of experience as well as a determinant of how experience is perceived and understood, and cognitive development in response to experience forms part of learning but also impacts on learning. This definition of cognition and how it is developed has a relationship to the concept of transformational learning (Merriam, 2004; Mezirow, 2003).

In this paper we describe our experience working with resource poor smallholder farmers in Eastern India. That experience took place at the interface between PRADAN an Indian non-government organisation (NGO) and the communities with which it works and involved various researchers from Australian universities. The experience was located within the approach that PRADAN normally takes to engage with communities. That approach focuses first and foremost on enhancing the capacity and sense of agency of women within those communities. The production aspects of this project are outlined in Kumar et al (2015).

Materials and Methods

This project works with groups of women who farm in rural environments. The groups are not formed by the project but are women's self-help groups (SHGs) developed by PRADAN a non-government organisation (NGO). SHGs are associations of small numbers of women (usually between 10 and 20) who share socio-economic backgrounds and live in the same village. The SHG has several roles including the provision of mutual support, identification and promotion of small-scale enterprises and development of a savings fund that can be used to provide loans to members of the SHG. Most women in rural SHGs are directly involved in agricultural production. These groups are not formed as learning or agricultural development groups.

The project introduced on-farm, farmer-managed agricultural research and built an action learning cycle grounded in agricultural production. The project therefore, provides a further opportunity for women in SHGs to enhance their lives through a focus on learning and research. Farmers are involved in all stages of the cycle (Figure 1). An important part of the approach is the integration of the action research cycle (Figure 1) with PRADAN's approach to build the sense of agency of members of the SHG.

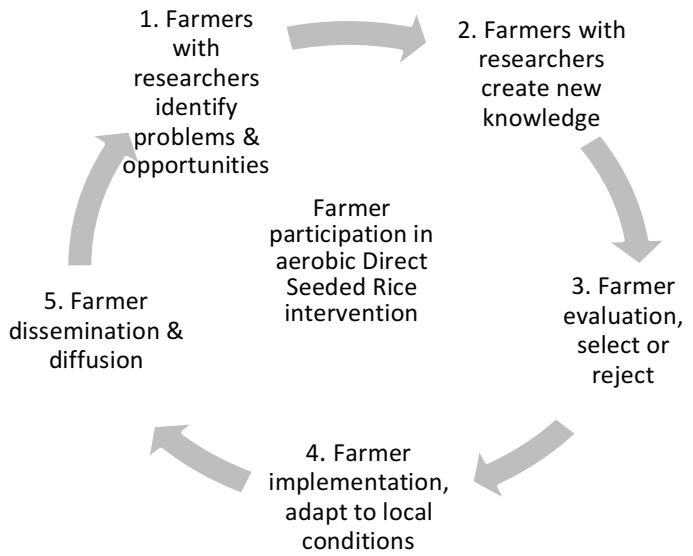

Figure 1. Smallholder farmers are involved in all stages of the innovation cycle.

Results

The results from this work take several forms and include those that can be observed such as changes in practice by farmers and explanations by farmers of those changes in practice and the processes for their

development and adoption. In addition, results also include changes at a higher level and take the form of statements by farmers in relation to how their lives have changed during the time of the project. Linking the results obtained to broader bodies of theory and where appropriate the development of new theory are also elements of the results in this work.

In a structured workshop farmers outlined changes that had occurred in their lives in the last three years to evaluate the role the project had on their lives. Women stated that in many cases their lives had been transformed and they were able to provide concrete examples illustrating that change. The changes were similar at several sites but were not always exactly the same. Both women and men farmers had moved from a day to day survival mode where they were "only able to think about tomorrow and no further ahead" to one that involved planning on an annual cycle with that planning involving flexibility to change cropping regimes due to changes in seasonal conditions. This change demonstrated a shift in their thinking processes that can be considered as cognitive shifts; that is shifts in the way in which they make sense of and react to their environment. Further examples of such shifts demonstrated in the workshops are provided in Figure 2. The shifts suggest that learning processes are related to the cognitive position of the individual and that experiences are interpreted in relation to that position.

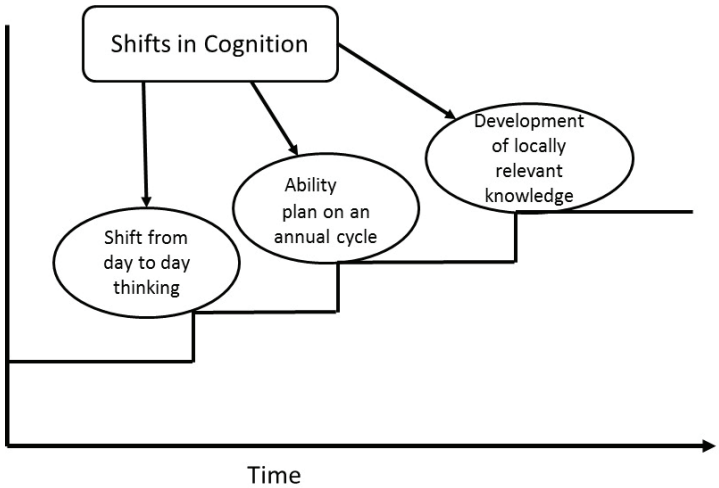

Figure 2. Conceptual model of cognitive transformation over time in smallholder farmers

At the initial stage farmers were only able to work on a short planning time frame, they started, as a group in association with the project team, to develop alternative views of their resources and cropping activities producing a shift in their cognition and how they viewed their situation, following further development they became able to understand and work with an annual planning cycle a second step in cognition, the third step related to their becoming adept at developing research questions and carrying out field trials to the stage where they can independently develop their own locally relevant knowledge. Therefore, introducing concepts that require annual planning to a person who is still focussed on day to day survival will not be taken up by that person because they are not able to work with those concepts.

Because the external environment (including physical, social, economic and political environments) has changed over the time it is difficult to make definitive statements on causal links between the project and people's lives. However, the evidence that supports the impact of the approach is building. Evidence that the whole approach is important rather than some element of the approach alone is also developing.

Discussion and Conclusions

In this project we are developing people rather agricultural technology, or even farming systems. However, as a result of participating the people are positioned to modify, adapt and monitor their farming system in line with their needs and resources. Farmers involved with the project demonstrated transformative change. The change was expressed in various ways including:

- Changes in participants approach to their lives including their ability to meet and communicate with people from outside the community
- Changes in how they viewed and made use of the resources they held, demonstrated through changes in agricultural production systems

- Major shifts in thinking including the ability to plan in longer time periods – moving from only being able to plan for the next day to an annual planning cycle
- Development of the ability to develop and carry out on-farm trials to evaluate alternative approaches to their production systems and develop their own locally relevant knowledge, illustrated through trial work carried out by farmers

The project did not focus on the provision of additional physical resources but rather on the way in which people functioned, understood and made use of the resources they held. The project outcomes provide important evidence that the change in the people needed to come first and that change was not just in the farmers but also in those who were working with them. Our experience reinforces that the poor and disadvantaged can be highly innovative, provided they are appropriately supported through a process of relevant learning that builds their cognition. On-farm agricultural research provides a context for transformative learning to take place.

An important element in our learning from this project is that there is no short-cut to farmer learning, it is not a quick fix. The learning needs to be aligned with the point at which farmers are starting in relation to both their cognitive and affective states. In addition, the learning needs to be transformational and as we know from our own personal experience transforming ourselves, our knowledge and how we apply that knowledge takes time. However, the benefits justify the higher costs. Once transformed through this learning process, farmers have demonstrated enhanced capacity for independent innovation. They become more resilient to future complexity and uncertainty, and less reliant on government welfare programs.

As part of the project work is being carried out to determine the mechanisms behind the learning and its relationship to learning and development theory. Individual learning can be explained in relation to cognitive development and cognitive development appears to have a path dependency, that is, some forms/elements of cognitive development are required before others can occur. Learning can be cognitive and lead to a shift in the way in which a person perceives and relates to their experiences (inquiry based) or their technical skills enabling development of a higher level of skill in the performance of an activity such as the planting of rice. Individuals learning in various ways but most learning can be considered to be based on an experience or collection of experiences. Learning is generally regarded as an individual activity though almost all learning takes place in a social context and within groups. While the learning is taking place in a group the implementation of that learning is individual or in another group, usually the household or family. Therefore, where field trials are carried out the field belongs to the farmer but the learning belongs to the group.

The work outlined in this paper is preliminary but compelling. It is not possible at this stage to attribute the proportion of the change that is due to the project and the approach being taken in that project. There does appear to be a difference between community members who are involved with the project and those who are not; more evidence is required to support this observation.

Acknowledgements
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Profitable crop sequences to reduce ryegrass seed bank where herbicide resistant ryegrass is a major constraint to the sustainability of cropping systems

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Abstract
The profitability of cropping sequences involving pulse break crops (grain or brown manure-BM), canola and wheat high and low input (H & L), fallow and cereal hay and the respective effectiveness of each treatment in reducing the seed bank of an annual ryegrass (ARG) population resistant to multiple post-emergent herbicides, was investigated at Eurongilly in southern NSW between 2012 and 2015. Sequences that involved either canola or a spray topped lupin grain crop in year 1 followed by cereal hay or RoundupReady (RR) canola in year 2 provided high gross margins and significantly reduced ARG seed bank over the 3 year crop sequence. Cheaper double break combinations using a fallow or pulse BM in year 1 followed by RR canola in year 2 resulted in lower gross margins, but were the most effective in reducing the seed bank. The seed bank at the site changed from 1815 seeds/m² in year 1 to between 56 and 3140 seeds/m² at the conclusion of the experiment depending on crop sequence. RR canola in year 1 followed by high input wheat (Sakura® pre-em & post emergent Boxer Gold®) in year 2, and wheat (Sakura®) in year 3 was the most profitable sequence, but was less effective at reducing the seed bank (219 seeds/m²) compared to most double break options (56-142 seeds/m²) with the exception of triazine tolerant (TT) canola followed by cereal hay (300 seeds/m²).

Key words
Canola, cereals, crop sequences, herbicide resistant ryegrass, pulse legumes, wheat.

Introduction
There is substantial evidence indicating wide-spread resistance or partial resistance of ARG (*Lolium rigidum Gaudin*) to a wide range of herbicide groups (Broster et al 2011) across south eastern Australia. Consultation with grower groups and agribusiness collaborators identified difficulties in managing grass weeds as a main constraint to wheat production, and the primary driver of decisions to grow broad leaf break crops. This paper outlines the main findings to date on sequence profitability and effectiveness at reducing seed banks of herbicide resistant ARG from experiments that examined the impact of different inputs and herbicides applied to canola, pulse legumes, or wheat crops. The experiments address two key questions:
(1) Do crop sequences that include a break crop improve the profitability of subsequent cereal crops in the presence of herbicide resistant ARG?
(2) Can herbicide resistant ARG be managed more cost-effectively under break crops than cereals?

Methods and Materials
Experiments were established in 2012 in a paddock at Eurongilly in south-eastern NSW on red chromosols (Isbell, 1996) where herbicide-resistant ARG was known to be present with seed bank of 1815 plants/m2. The susceptibility/resistance of the ARG was tested by Plant Science Consulting SA. Results indicated that the ARG was resistant or partially resistant to group A herbicides Haloxyfop (70%), Clethodim (55%), Pinoxaden & Cliquintocet-methyl (65%), and Group B herbicides Iodsulfuron-methyl-sodium (95%), but 100% susceptible to one Group A herbicide, Butroxydim and to Group M (Glyphosate). The crops/treatments established in the each of the three years were:
- Year 1: Canola (RR & TT), legumes (pulse grain or brown manure), wheat (High & Low input) or fallow;
- Year 2: Canola (RR), wheat (high or low input) or cereal wheat (Hay);
- Year 3: Wheat.

Two input rates, high (H) or low (L) were included for wheat treatments with the (H) treatments used to examine a combination of effects including: 1) new but expensive pre- and post emergent herbicides 2) increased sowing density for increased competition 3) higher fertiliser rates (nitrogen and phosphorus) in

canola and wheat for increased early vigour and competition. In the (H) treatment, the total input costs were significantly greater than (L) treatments, but they had the potential to return higher yields and gross margins (GM). Plant density aimed for in the canola, lupin and field peas (BM) were 40 plants/m2, lentils at 120 plants/m2, wheat (H & L) at 75 and 150 plants/m2. Canola was seed dressed with Jockey® & Gaucho® and fertilized with MAP @ 25 & 75kg/ha (TT & RR) with wheat (L & H) seed dressed with Raxil® or Dividend® and fertilized with MAP @ 25 & 75kg/ha, respectively. All treatments had an initial knockdown spray of Glyphosate 450 @ 1.6 L/ha. A brief outline of herbicides is summarised below. Detailed information is available on request.

Year 1 treatments imposed, input/risk categories and input costs (2012):
1. TT Canola*:* cv. Crusher open pollinated; NH4SO4 (100 kg/ha) pre-sow, urea top dressed (100 kg/ha). Triflur®X @ 2 L/ha + Atrazine 900 @ 1.1 kg/ha; Factor® @ 80 g/ha + Atrazine 900 @ 0.9 kg/ha. Total input cost = $249/ha.
2. RR Canola*:* cv. Hyola®505 hybrid; NH4SO4 (100 kg/ha) pre-sow, urea top dressed (200 kg/ha). Triflur®X @ 2 L/ha, Round-Up Ready® @ 0.9 kg/ha at 2-3 leaf & 6 leaf. Total input costs = $427/ha.
3. Fallow: fallow established in September 2012 with an application of Glyphosate 450 @ 2 L/ha, Ally® @ 5 g/ha, double knocked with Gramoxone® 250 @ 2 L/ha. Total input costs = $35/ha.
4. Field peas & Lupin BM: cv's Morgan & Mandelup. Triflur®X @ 2 L/ha + Simazine 900 @ 1 kg/ha; BM spray of Glyphosate 450 @ 2 L/ha + LontrelTM @ 150 ml/ha + Hammer® @ 25 ml/ha (early September); Glyphosate 450 @ 2.5 L/ha (mid October). Total input costs = $120/ha and $129/ha, peas and lupins, respectively.
5. Lupin grain: cv. Mandelup. Triflur®X @ 2L/ha + Simazine 900 @ 2.2 kg/ha; Factor® @ 180 g/ha; spray top with Gramoxone® 250 @ 400 ml/ha (mid November). Total input costs = $168/ha.
6. Wheat (L): cv. Spitfire; urea @ GS30 (100 kg/ha). Triflur®X @ 2L/ha + Diuron 500 @ 1 L/ha; Boxer®Gold @ 1.5 L/ha at 2-3 leaf stage. Total input costs = $169/ha.
7. Wheat (H): cv. Spitfire; urea @GS30 (200 kg/ha). Sakura® 850WG @ 118 g/ha + Avadex® Xtra @ 2 L/ha; Boxer®Gold @ 2.5 L/ha and Axial® @ 150 ml/ha at 2-3 leaf stage. Total input costs = $430/ha.

Two sowing times in 2012 were late April (canola and lupin) and mid May (field peas BM and wheat). All plots were kept weed-free during summer fallow period. Initial plots were 40m in length x 1.8 m with each treatment replicated four times.

Year 2 treatments (wheat or second break crop) in 2013: All plots from year 1 were split into three sub-plots. Four treatments were sown in early May 2013 being RR canola, wheat (H & L) and cereal hay (wheat). Wheat (H & L) was sown into all year 1 treatments and RR canola was sown into pulse, wheat or fallow year 1 treatments only. Cereal hay was sown into canola year 1 treatment to act as a double break. Nitrogen as urea was differentially applied to all year 2 treatments to achieve a wheat grain yield of 7 t/ha in the wheat (H), 4 t/ha in the wheat (L) and 3.5 t/ha in canola based on mineral N concentrations measured prior to sowing. The herbicides used in year 2 were similar to those used in year 1 for the respective crop and input category.

Year 3: All plots were sown to wheat cv. Suntop (Dividend®) + MAP + Impact® @ 75 kg/ha. Herbicides included Weedmaster®ArgoTM (1.9 L/ha), Hammer® (45 ml/ha), Sakura® 850WG (118 g/ha), Avadex®Xtra (2 L/ha). Urea was top dressed at GS30 between 87 and 187 kg/ha to achieve a target wheat grain yield of 5 t/ha for all treatments based on levels of mineral N measured prior to sowing in different treatments.

In late March year 1 (pre-experiment), forty surface soil cores (6cm in diameter x 5cm deep) were randomly removed across the trial area with eight surface cores removed per treatment in April of year 2, year 3 and year 4 to measure changes in ARG seed bank. The soil was put into trays and watered over the following three months and all emerged ARG counted. GM were calculated using input costs and operations from SAGIT/NSW DPI GM books and commodity prices on day of harvest from cash prices at GrainCorp terminal at Junee, NSW.

Results

Crop yields and gross margins

In year 1 the most profitable crops were RR and TT canola which returned grain yields and gross margins of 3.5t/ha (GM =$1259/ha) and 3t/ha (GM = $1166/ha), respectively. The next most profitable crops were lupins (H) @ $683/ha (yield = 3.1t/ha), wheat (H) @ $257/ha (yield = 3.2t/ha), wheat (L) @ $250/ha (yield = 2.0 t/ha), with the brown manure or fallow treatments having negative returns (-$45 to -$250/ha). In year 2, the treatments with the highest gross margin were canola following fallow or brown manure treatments (> $1000/ha, grain yield avg = 3.5t/ha) with canola following wheat (H) or lupins (H) returning ~$900/ha (grain yield = 3.2t/ha). Over the 3 years, the most profitable sequence was RR canola - wheat (H) - wheat, with an average GM of $883/ha/yr. Sequences with the highest average annual gross margins >$800/ha/yr were treatments that had canola (RR or TT) in year 1, with the next most profitable group having grain lupins in year 1 or canola year 2 (> $600/ha). The third group included sequences of fallow, combinations of wheat (H or L) or lentils in year 1, with the final group involving sequences with BM crops followed by wheat (H or L) (Table 1).

Interaction between crop treatments and ryegrass plant populations

ARG panicles (m^2) in spring year 1 in untreated areas were 1042, significantly more than wheat (L) with 534 panicles/m^2. All other treatments in year 1 had significantly less panicles than wheat (L), but the most effective ARG control was achieved by fallow, pulse BM or canola (H) (Table 1). By spring in year 2, there were significant differences in panicles/m^2 with four distinct categories (0-8, 14-71, 192-388 & >643 panicles/m^2) (Table 1). Main year 2 treatment effects continued into year 3 with significantly less panicles in order of: canola < hay = wheat (H) < wheat (L), and year 1 effects: fallow < pulses < canola = wheat (H) < wheat (L). Interactions were categorised into groups of (0-30, 60-166, 199-370, >536 panicles/m2) (Table 1). Generally, double break sequences or those where wheat (H) treatments were grown following treatments with bare soil or less stubble from year 1 had significantly fewer panicles.

By autumn year 2, there was a significant three-fold increase in ryegrass seed bank populations (5492 seeds/m^2) following wheat (L) and by autumn year 3 a further significant 2.5 fold increase (13148 seed/m^2) after a second wheat (L) treatment. Comparatively, seed bank numbers reduced to 124 seeds/m^2 where canola (H) 2012 was followed by wheat hay (2013), and double breaks involving legumes, canola, fallow or hay resulted in the lowest seed banks following the 3 year sequences (Table 1). Main effects from year 1 and year 2 treatments were still apparent after the conclusion of the experiment in March 2015, with the year 2 treatments having a greater effect with significantly higher seed bank numbers remaining in order of: wheat (L) > wheat (H) > wheat (hay) > canola (meaned data not shown). The expensive herbicide costs ($142/ha) associated with consecutive wheat (H) treatments resulted in a significant reduction in seed bank by November 2014 (366 plants/m2), but was not as effective as sequences involving break crops or a fallow.

Discussion & Conclusion

In the presence of a high population of herbicide resistant ARG, sequences that include a break crop were more profitable compared to continuous wheat (H or L). Canola was consistently the most profitable break crop, largely due to the high returns from canola itself, but legume grain crops were profitable and provided additional N in year 2. Although the TT canola / wheat (H) sequence was profitable, it was not as effective at reducing the ryegrass seed bank and any sequence with wheat (L) resulted in an increase in ryegrass numbers. Break crops or fallow provided cheaper and more effective ARG control options. Two consecutive years of complete ARG control were required to reduce seed banks to managable levels. The most profitable double break sequences were RR canola followed by a cereal hay or grain lupins followed by RR canola with these sequences also very effective at reducing the seed bank. Sequences involving fallows and brown manures reduced production risk in subsequent years due to enhanced yield in the following wheat crops, but were not as profitable as continuous cropping.

Table 1 Average annual gross margin over 3 years compared to ryegrass seedbank (April 2013, 2014, 2015) and ryegrass panicle number (November 2012-2014) in Exp 1 at Eurongilly, NSW.
Crop 2012 pre-treatments are arranged in order of descending SEEDBANK March 2015 seed counts..

Crop x Input 2012	Crop x Input 2013	Ryegrass panicles Nov 2012	SEEDBANK March 2013	Ryegrass panicles Nov 2013	SEEDBANK March 2014	Ryegrass panicles Nov 2014	SEEDBANK March 2015	Average Annual 3yr GM
(Year 1)	(Year 2)	(panicles/m^2)	(seeds/m^2)	(panicles/m^2)	(seeds/m^2)	(panicles/m^2)	(seeds/m^2)	($/ha/yr)
Fallow	Canola	0 (NM)^	290	0	NM	2	56	$603
Lupin grain	Canola	43*	748	0	196	6	63	$790
Lupin BM	Canola	0 (NM)^	152	0	NM	1	110	$552
Fallow	Wheat (H)	0 (NM)^	290	2	NM	10	118	$539
RR Canola	Wheat (Hay)	0	208	0 (537)^	124	23	122	$834
Pea BM	Canola	0 (NM)^	464	0	210	4	142	$513
Lupin grain	Wheat (H)	43*	748	8	312	19	148	$757
Pea BM	Wheat (H)	0 (NM)^	464	2	496	14	162	$486
RR Canola	Wheat (H)	0	208	15	381	29	219	$883
TT Canola	Wheat (H)	32	505	14	NM	82	252	$844
Wheat (H)	Canola	78	777	0	259	20	267	$636
Lupin BM	Wheat (H)	0 (NM)	152	2	NM	11	279	$463
TT Canola	Wheat (Hay)	32	505	0 (790)^	NM	23	300	$844
Wheat (L)	Canola	504	5492	0	797	22	332	$582
Wheat (H)	Wheat (H)	78	777	29	1379	60	366	$585
Wheat (L)	Wheat (H)	504	5492	71	3412	121	523	$537
Fallow	Wheat (L)	0 (NM)^	290	56	NM	100	970	$530
Lupin BM	Wheat (L)	0 (NM)^	152	192	NM	308	1105	$419
Lupin grain	Wheat (L)	43*	748	200	6614	122	1167	$715
Wheat (H)	Wheat (L)	78	777	294	5508	147	2158	$513
TT Canola	Wheat (L)	32	505	383	NM	229	2222	$800
RR Canola	Wheat (L)	0	208	388	7770	200	2387	$845
Pea BM	Wheat (L)	0 (NM)^	464	237	7413	157	3118	$397
Wheat (L)	Wheat (L)	504	5492	898	13148	943	3140	$388
P value (2012)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
P value (2013)			NA	<0.001	<0.001	<0.001	<0.001	
P value (interaction)			NA	0.004	0.105	<0.001	0.699	

*Lupins spray topped in Nov 2012 prior to ryegrass seed maturity
^Ryegrass panicles estimated at zero in 2012 and 2013 due to either spraying or cutting of hay prior to seed set
NM Not measured

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Weed management as a key driver of crop agronomy

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Abstract
Weed control objectives are increasingly determining how cropping systems are managed. This study examines the current influence of weed management across 13 major grain growing zones of the western, southern and northern cropping regions of Australia. Information from 602 farms was collected in 2014 and used in conjunction with ABS statistics on crop production and information from a range of regional sources to quantify herbicide and non-herbicide practice use and costs. Growers are demonstrating an ongoing willingness to invest heavily to avoid yield losses and large weed seedbanks. Consistent with findings from paddock surveys, weed densities in crop are typically being kept low, even in the presence of increasing herbicide resistance. In addition to herbicide use, this involves increasing use of practices that reduce stubble retention levels. The results also show how weed constraints are reducing the area sown to otherwise preferred cereal crops. Increasing herbicide resistance and other new weed challenges mean that grower efforts to maintain low weed densities are having rapidly intensifying implications for cropping systems.

Key words
Integrated weed management, herbicide resistance, cultivation, burning, stubble retention

Introduction

The availability of cost-effective herbicides since the 1980s enabled Australian farming systems to shift away from cultivation and rotation-based weed control. At the same time herbicides provided such effective and readily available weed control that to a large extent other aspects of crop agronomy (e.g. crop choice, cropping intensity, stubble management, time of sowing, row spacing) could begin to be considered almost independently of weed management decisions. The preferred cropping systems that have evolved are now under increasing pressure from new and evolving weed management challenges. In addition to herbicide resistance (e.g. Owen et al. 2014; Boutsalis et al. 2012; Walker et al. 2011) , these challenges include shifts in weed populations associated with changes in tillage regimes and more frequent cropping (e.g. Kleeman and Gill 2013), the herbicide tolerance of some summer-growing weed species, and new weed incursions.

Effective weed management in cropping systems involves managing a range of constantly evolving targets with shifting priorities and threats. The last major national study of the distribution and economic impact of weeds in Australian cropping systems was conducted 15 years ago (Jones et al. 2000). The results presented in this paper are part of a larger Grains Research and Development Corporation (GRDC) supported study to quantify the costs of weeds and their management across Australian grain growing regions, crops and weed types. A general aim is to identify where and how the greatest weed management costs are being incurred and to inform R, D & E investment in improved weed management strategies. Here the focus is on the weed management practices and trends that are challenging the ability of agronomists and researchers to consider optimal crop agronomy independently of what growers need to do to meet weed management objectives.

Method

The study covers the 13 major agro-ecological zones (AEZs) across the western, southern and northern grain growing regions and the major crop types of wheat, barley, oats, canola, pulses and grain sorghum (see AEZ list in Figure 1 and www.grdc.com.au/uploads/documents/grall.jpg). The relatively small Tasmania grain and Victoria high rainfall AEZs were merged for the purpose of this study.

Farm-level data for the analysis were drawn from interviews conducted March to July 2014 with 602 grain growers selected at random to represent each agro-ecological zone, used in conjunction with ABS statistics

on crop production and information on practice costs from regional agronomists and a range of other sources. Respondents needed to be identified as primary cropping decision makers and have a crop area greater than 500ha of crop, with the exception of the High Rainfall Victoria and Tasmanian zone (250ha). Based on the total number of primary cropping decision makers directly approached for participation, the response rate was 44%.

For the purpose of determining the cost of weeds in grain production as a function of losses due to reduction in crop returns and expenditure for weed control, data on typical in-crop weed densities (and type) and weed control practices were collected. These included herbicides (knockdown, pre-emergent, post-emergent, fallow weed control, and herbicides for croptopping, spraytopping, manuring/hayfreezing and double knockdown), cultivation, burning stubble, manuring, mouldboard ploughing to bury weed seeds, delayed seeding (with knockdown herbicides), chaff carts and narrow windrow burning. The extent of use of each practice was collected along with the year that the practice was first used on the farm, allowing trends in adoption across regions and AEZs to be identified. For cultivation and burning, growers were asked to apportion the reasoning for their use to weed management relative to other possible reasons for implementing these practices (e.g. disease and pest management). The influence of weeds on crop choice (e.g. growing a less profitable break crop or pasture rather than a cereal due to grass weeds) was investigated by asking what crop area changes would be made if weed management was not a consideration.

Results and Discussion

Respondents commonly had cropping with some livestock (73%) and had an average age between 55-64 years old, with 20% younger than 45 years. The average annual crop area was 1981ha and 58% pay a consultant for cropping advice. A majority (82%) grew either pulses or canola in addition to cereals. In the northern region, 58% grew sorghum.

Weed control

Overall, 54% of growers stated that their most common weed competing with cereal crops later in the season is usually only present at less than 1/m^2. Only 11% reported densities greater than 10/m^2. This is consistent with previous multi-year field studies where it was found that growers generally only allow low weed densities to survive past mid-season, including populations with high levels of herbicide resistance (Llewellyn et al. 2009). In a 2010 study that inspected 466 Western Australian cropping paddocks, only 5% were assessed to have an annual ryegrass density (the most common weed) greater than 10 plants/m^2 (Owen et al. 2012). The five most common weeds identified by growers as competing with cereal crops later in the season were annual ryegrass, wild radish, wild oats, brome grass and wild turnip.

Weed management practices

Weed management is the most important reason for cultivation prior to seeding (Table 1). Overall, 71% of growers seeding with prior cultivation cite weed management as a main reason for their use of cultivation. Although no-till is the most common seeding system, in the southern region 27% of land is cultivated at or prior to seeding. Cultivation in fallows for the primary purpose of weed control is more common, particularly in the northern region (Table 1) and Central NSW AEZ. Burning of crop residues is common and primarily for weed control, except in the northern region. Narrow windrow burning, a practice that can remove approximately half of crop residue (Walsh and Newman 2007), is particularly common in the western region (Table 1) but use is rapidly increasing in other AEZs (Figure 1).

Table 1. Use of practices for weed management.

	Southern	Western	Northern
Cropping land cultivated prior to or at seeding (i.e. not under zero or no-till) (%)	27	9	20
Growers who cite weed management as the main reason for cultivation prior to seeding as proportion of growers seeding with prior cultivation (%)	67	76	78
Growers who cite weed management as main reason for cultivation prior to seeding expressed as proportion of all growers (%)	30	15	27
Growers using cultivation of fallows primarily for weed control (%)	37	30	66
Area to be cropped that is cultivated during the fallow by users (%)	31	19	28
Growers burning stubble – whole paddock (%)	52	40	12
Cropping land burnt by users – not including windrow burning (%)	19	11	3
Growers who cite weed management as the main reason for burning (whole paddock) as a proportion of users (%)	66	68	29
Growers using narrow windrow burning (%)	28	51	4
Proportion of crop area treated with narrow windrow burning by users (%)	23	30	23

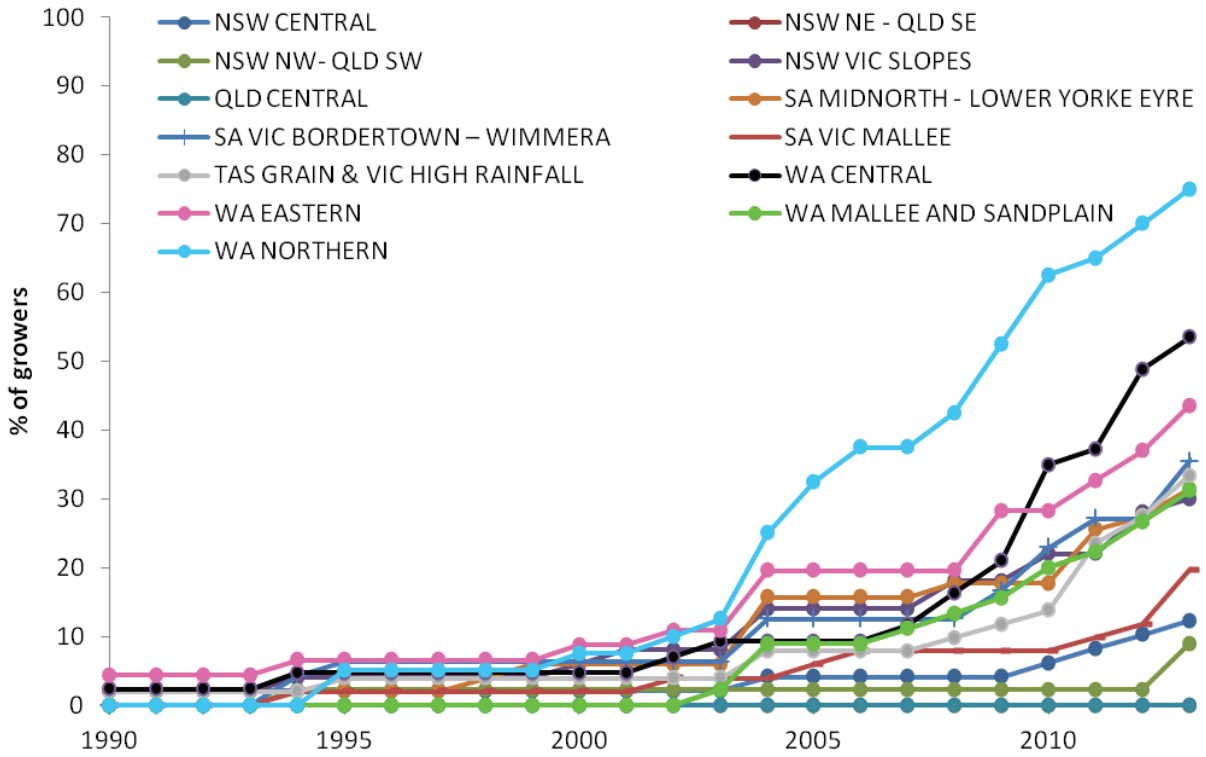

Figure 1. Cumulative adoption of narrow windrow burning by agroecological zone (% growers who have used the practice)

Crop choice

Another impact of weeds is on crop sequence and land use decisions. The results show that weed considerations influence land use and crop choice for a substantial number of growers. Growers were asked if they would change the areas of what they would grow if they had no weed considerations. In the western region 26% said they would change what they grow; 25% in the southern region and 32% in the northern region. Most commonly growers would grow more cereals (mainly wheat) if weeds were less influential.

Conclusions

Australian grain growers invest heavily in practices to keep weed densities and subsequent crop yield losses low. This is contributing to increasingly extensive crop residue burning, cultivation and influences on crop choice primarily driven by weed management objectives. The development and implementation of optimal

crop agronomy and farming systems cannot be considered independently of the constraints caused by increasingly challenging weed populations.

Acknowledgements
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“Buying a spring” – the water and nitrogen cost of poor fallow weed control

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Abstract
Research in southern NSW demonstrated that 50% of yield potential can be attributed to summer rainfall and summer fallow management as a result of increased stored water (increased by 49 mm) and nitrogen (N) (increased by 49 kgN/ha). This paper reports experiments conducted near Forbes in central NSW (2011 & 2012) to further evaluate the impact of summer weed control on subsequent crop yield, to investigate interactions with other macro-nutrients (P, K and S) and assess the profitability of replacing lost N (via summer weed uptake) with N fertiliser. Controlling summer weeds increased canola grain yield by 1.0 t/ha due to increased stored water (85 mm PAW) and mineral N (69 kgN/ha) at sowing. For every 1mm of stored water stored through summer weed control, soil mineral N increased by 0.6 kgN/ha. Summer weeds had no significant impact on topsoil P and K levels, or S to a depth of 90cm. Every $/ha invested in fallow herbicides returned $8/ha. Despite poor topdressing conditions, profitability of applying N fertiliser improved from $1 return on every $1 invested when weeds were not controlled to $3 return on every $1 invested in the complete weed control treatment. The study demonstrates the value of strict summer weed control to improve productivity and resource-use efficiency in southern cropping systems.

Key words
Water use efficiency, summer fallow management, summer weed control, nitrogen use efficiency.

Introduction
This experiment was part of a series of summer fallow management experiments funded by GRDC through the Central West Farming Systems “Rain & Grain” project. In three experiments conducted in a single year (2010), Haskins and McMaster (2012) found that complete control of summer fallow weeds increased subsequent wheat crop yield by 50%. Summer weed control was more important than stubble management as weed-free fallows increased both water and N availability. A dollar invested in herbicide to maintain fallows weed free averaged a $ 3.90 gross return across three experiments (Haskins and McMaster, 2012).

The aim of this experiment was to evaluate the impact of summer weed control during the summer fallow period on stored soil water and N, and the impact on subsequent grain yield over a further two years (2011 and 2012) as seasonal interactions on the value of stored water are likely. In addition, previous studies on effects of summer fallow weed control (Haskins and McMaster 2012, Hunt *et al*. 2013) considered effects on water and N, but not impacts on other macronutrients (P, K and S).

Methods
The experiment was conducted over two seasons (2011 and 2012) at a site located 30 km north west of Forbes NSW. A factorial design with three replications, four weed control treatments (Table 1) and three N fertiliser rates (0, 70,140 kg/ha N in 2011 and 0, 50, 100 kg/ha N in 2012). The weed control treatments ranged from no control (Nil) to complete control, with intermediate levels including missed or delayed treatments (Table 1). Individual plot size for each weed control treatment was 12m x 12m and all experiments were sown on 29 April (575CL canola - 2011) and 5 May (Bounty wheat - 2012) using a commercial seeder with narrow points and press wheels. The N fertiliser treatments (2m x 12m) were applied at early budding with urea ammonium nitrate (streaming nozzles) in 2011 and predrilled with urea in 2012 (plot seeder). Fertiliser (80 kg/ha MAP) was applied with seed. But no further nutrients were applied.

Table 1. Protocol for summer weed control treatments

Weed control treatment	Protocol
Nil	No summer spray (knockdown applied just prior to sowing)
Miss first	The first initial spray of the fallow period was not applied
Complete weed control	Herbicides applied approx 10 days after significant rainfall event (>20mm)
Delayed	Herbicides applied approx 24 days after a significant rainfall event (>20 mm)

Results

The seasonal conditions at the site were close to average in terms of long-term mean rainfall and both years experienced above-average February and March rainfall, but relatively low in-crop rainfall (Table 2). This rainfall pattern was likely to highlight the value of summer fallow management as significant rain occurred in summer while spring rainfall for crop growth was low.

Table 2. Monthly rainfall (mm) at Gunningbland.

Year	Rainfall (mm)												Total (mm)	In-crop (mm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2011	8	70	83	25	34	12	17	57	23	56	139	102	626	136
Decile	1	7	9	4	4	1	2	7	3	6	10	9		
2012	35	179	128	37	60	44	43	15	33	7	18	14	613	202
Decile	4	10	9	6	7	5	5	1	5	0	2	2		

Effects of fallow management on soil water

Complete control of summer weeds increased the amount of water available to the subsequent crop by 86 mm in 2011 and 50 mm in 2012 relative to the nil treatment (Table 3). Stored soil water in 2011 for the full (201 mm) or delayed (167 mm) treatment was greater than either the missed first (122 mm) or nil (115 mm) spray treatments (Table 3). The complete, delayed and miss first spray treatments also stored more water than the nil spray in 2012 with 147, 159, 155 and 97 mm PAW, respectively (Table 3). This may have been influenced by the higher rainfall over the summer fallow period in 2012 (Table 2).

Table 3. Effect of weed control treatment on plant available water (mm) and mineral N (kgN/ha)

Weed control treatment	Plant available water (mm)		Mineral N (kgN/ha)	
	2011	2012	2011	2012
Nil	116	97	44	80
Miss first	122	155	72	121
Complete	201	147	114	126
Delayed	168	159	82	113
l.s.d (P=0.05)	43	37	36	21

In both 2011 and 2012 the additional PAW was conserved between 15cm and 105cm depth. Summer weeds in the nil spray treatment reduced PAW to a depth of 120 cm (Figures 1, and 3 4). Soil water was measured after the 2011 harvest (115 mm PAW) with no difference between the spray treatments (data not shown).

Effect of fallow management on macronutrients

Summer weeds had a significant effect on available soil nitrogen at sowing in 2011 (P=0.02) and 2012 (P=0.007) (Table 3). Complete control increased the level of mineral nitrogen by 69 and 45 kg N/ha in 2011 and 2012, respectively. Nitrogen losses increased as weed control was delayed, missed or not applied in 2011, when compared to full spray treatment (Table 3). The nil spray treatment had lower mineral nitrogen levels in the soil when compared to the other three spray treatments. Increased nitrogen levels were evenly distributed throughout the whole soil profile (Figure 2 and 4). A strong relationship (R^2=0.62) was observed between PAW and nitrogen availability at sowing. For every millimetre of moisture that was lost through summer fallow weed growth, mineral nitrogen levels reduced by 0.56 kg/ha (Figure 5). The additional nitrogen benefit was likely due to a combination of increased mineralisation as the soil stayed wetter for longer where weeds were controlled, as well as reduced nitrogen loss through uptake by summer weeds.

Control of summer weeds did not influence the level of soil phosphorus (Colwell P), potassium (Colwell K) or sulphur (KCl) in either 2011 or 2012 (data not shown).

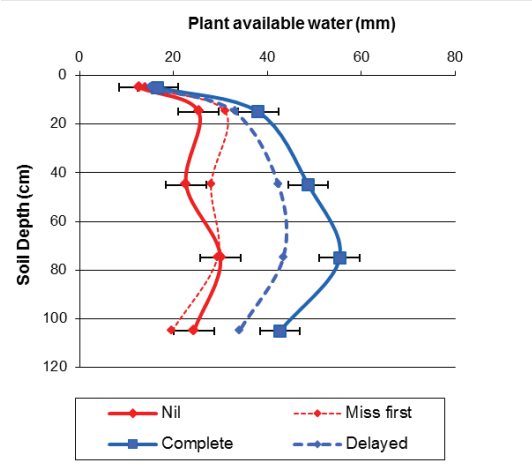

Figure 1. Plant available water profiles (mm) and standard error in 2011

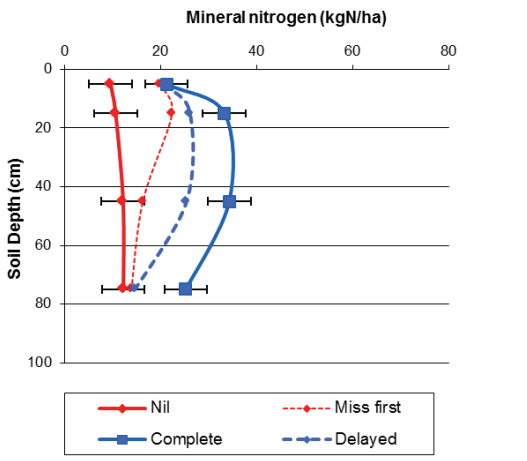

Figure 2. Mineral N (kgN/ha) profiles and standard error in 2011

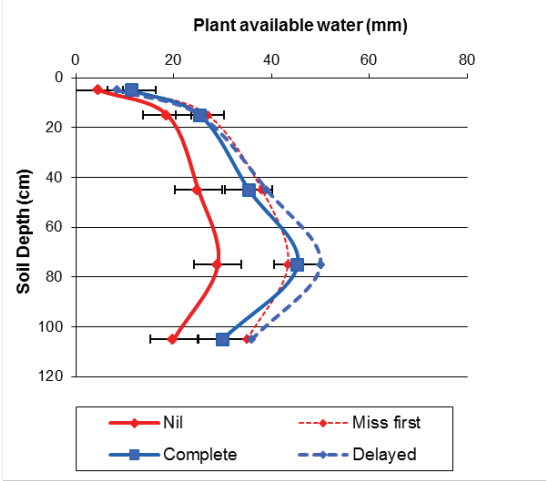

Figure 3. Plant available water profiles (mm) and standard error in 2012

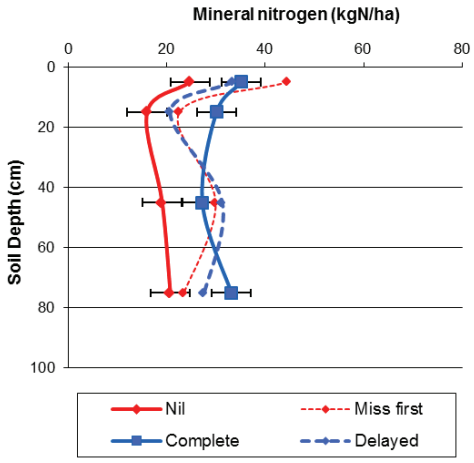

Figure 4. Depth and quantity of mineral N (kgN/ha) and standard error in 2012

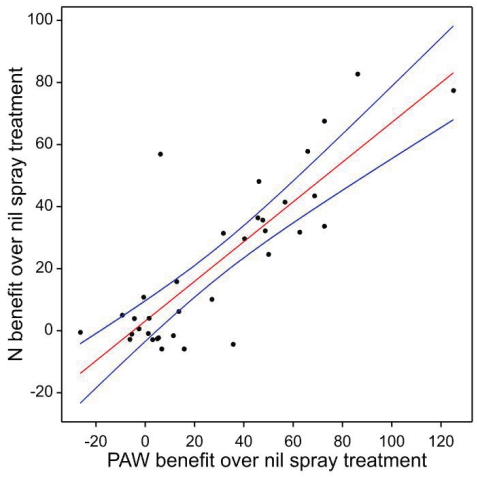

Figure 5. Fitted and observed relationship between PAW (mm) and mineral N (kgN/ha) loss by summer weed growth with 95% confidence intervals (across 2011-2012)

Impact of summer weed control and additional N fertiliser on grain yield and profitability

Grain yield was affected by summer weed control (P<0.001), additional N fertiliser (P<0.001) and their interaction (P=0.004) in 2011. In 2012, the experiment was accidently harvested by a commercial contractor at night. Canola grain yields for complete and delayed spray treatments (1.8 t/ha) were higher than the

missed first (1.3 t/ha) or nil (1 t/ha) spray treatments (Table 4). Additional N fertiliser increased grain yield from 1.1 t/ha to 1.4 t/ha and 1.8 t/ha respectively for 0 kgN/ha, 70 kgN/ha and 140 kgN/ha treatments. The effectiveness of additional fertiliser on grain yield varied with summer weed control. N fertiliser coupled with good summer weed control (increased stored moisture) gave the highest grain yields. For every dollar invested in fallow herbicides, the miss first spray treatment returned $1.90 /ha, the delayed spray treatment $3.90 /ha and full spray treatment $7.20 /ha (Table 4). The application of N fertiliser was not profitable in all treatments (Table 4) and did not match the returns of full weed control alone. Addition of N fertiliser with weed control increased return by a range of -$1.20 to $0.80 (Table 4). Seasonal conditions would strongly influence N uptake and hence ROI as no rain fell for 20 days after N application.

Table 4: Grain yield and economic analysis of summer weed control and additional nitrogen fertiliser treatments in 2011 Canola crop.

Spray treatment	Trt 1 - Spray treatment			Trt 2 - N fertiliser		Partial analysis			Total variable costs ($/ha)	Yield (t/ha)	Income ($/ha)	Gross margin ($/ha)
	No of sprays	Herbicide rate (low or high)	Cost ($/ha)	Rate (kgN/ha)	Cost ($/ha)	Cost ($/ha)	Benefit ($/ha)	Benefit cost ratio				
Nil	1	H	$24	0	$0	$24			$406	0.65	$323	-$83
				70	$119	$143	$196	1.4	$580	1.04	$519	-$61
				140	$238	$262	$267	1.0	$699	1.18	$590	-$109
Miss first	2	H, L	$42	0	$0	$42	$120	2.9	$479	0.89	$443	-$36
				70	$119	$161	$179	1.1	$598	1.25	$623	$25
				140	$238	$280	$381	1.4	$717	1.65	$825	$108
Complete	3	L, L, L	$54	0	$0	$54	$441	8.2	$491	1.53	$764	$273
				70	$119	$173	$59	0.3	$610	1.65	$823	$213
				140	$238	$292	$327	1.1	$729	2.18	$1,091	$362
Delayed	3	H, H, H	$72	0	$0	$72	$352	4.9	$509	1.35	$675	$166
				70	$119	$191	$220	1.1	$628	1.79	$895	$267
				140	$238	$310	$375	1.2	$747	2.10	$1,050	$303

Discussion

Summer weed control is a key profit driver for cropping systems in central NSW. Consistent with the results of Sadras et al. (2012) for South Australia and Hunt et al. (2013) for Victoria, crop profitability was maximised by complete control of summer weeds as a result of increased water and N availability. Controlling summer weeds provided 0.56 kgN/ha of nitrogen for every extra 1 mm of stored water in the soil profile (Figure 5). Water and N increase grain yield through grain number (more tillers and more grains per head) and grain size, and the ROI for controlling summer weeds in this and other reports (Haskins and McMaster, 2012) has been consistently between $2.20 - $7.20 ha for every dollar invested. The stored water was especially valuable because it was stored throughout the profile (>30 cm) and so available to the crops during the yield determining stage in the 30 days leading up to anthesis. Summer weed control would also presumably enhance early sowing opportunities in some seasons, which could increase grain yield by a further 21-31% (Kirkegaard & Hunt 2010). Summer weeds should be controlled when small and actively growing, as this lowers the rate of herbicide required and generally increases herbicide efficacy.

Acknowledgements

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Crop-topping and desiccation are valuable tools for weed control in pulses

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Abstract
Desiccation is the strategic termination of crop growth using herbicides. Crop-topping is the strategic in-crop application of knock-down herbicides to prevent seed set in weeds. These two operations can be combined to produce a more powerful management tool in pulses to control in-crop weed escapes and to advance harvest. This approach broadens weed management practices for pulses and strengthens their role in crop sequences of southern farming systems. Timing is critical and must be matched to the weed seed development, irrespective of the development stage of the crop. The pulse variety could suffer substantial yield losses if it has not reached physiological maturity at or before the timing of crop-topping/desiccation. Most current pulse varieties are late maturing and unsuited as significant yield losses occur. However, recent advances by Pulse Breeding Australia (PBA) have produced earlier maturing varieties of field pea, faba bean, lentil and lupin, much better suited to crop-topping, with a further array of untapped resources in gene-banks. Field pea has the added advantage of being late sown, thereby extending the pre-sowing window for weed control. Over the past three years at Wagga Wagga, many breeding lines of field pea, faba bean, lentil and lupin have been evaluated. Celine, PBA Pearl and PBA Oura were shown to be the best of the current commercial field pea varieties, but there is potential to further improve these from the vast germplasm available. A spread of application timings was applied to further refine this management tool.

Keywords
Farming systems, crop development, physiological maturity, crop sequences

Introduction
Pulses are an important and expanding component of cropping sequences in southern NSW (Armstrong & Holding 2015). They bring many advantages, particularly biological nitrogen fixation and crop diversification. A research and development priority at Wagga Wagga is to ensure weed control is not compromised during the pulse phase of the crop sequence; particularly as well managed farms in the region have a low tolerance for weed seed bank increases. To their advantage, pulses bring alternative herbicide groups and options, and can be used specifically to target grass weeds, particularly annual ryegrass and wild oats. They can be brown-manured if weed burdens are very high and are also suited to narrow windrow burning weed control in some situations. Peas bring a further advantage of being one of the latest sown crops in the planting calendar, thereby extending the pre-sowing weed control window. However, many pulse varieties are slow growing and compete poorly with weeds during the cooler winter months. Inevitably some weeds escape and set seed in spring. In these situations, crop-topping (Armstrong 2015) becomes a useful tool, ensuring the pulse phase maintains or lowers weed-seed banks.

Timing of the crop-topping/desiccation knock-down herbicide is critical and should be targeted at the milky-dough stage of the weed seed to ensure its sterilisation (McGillion & Storrie 2006). It is essential that development of the pulse variety must have reached or passed its physiological maturity by this time in order to avoid grain damage and associated yield losses. Many current pulse varieties are relatively late maturing (eg. chickpeas, lupins and Kaspa field peas) and therefore unsuited. Given the huge diversity of germplasm for development and maturity across pulse species, there is broad scope for selecting early maturing, high yielding lines specifically suited to crop-topping. Coincidently, many of the more recent varieties developed by Pulse Breeding Australia (PBA) are early, but this is largely a response to the increased frequency of shorter, dry springs over recent times.

This paper reports on preliminary findings of a crop-topping experiment conducted at Wagga Wagga in southern NSW in 2014. This investigation studied a wide range of pulse varieties with diverse phenology and a spread of spray timings from the end of flowering to maturity.

Methods

The trial was sown late (7 June 2014) to widen the pre-seeding weed control window. Eighteen pulse varieties and breeding lines with varying flowering and crop maturities were included. The experiment was set up in a factorial design with "spray times" the main blocks and "pulse varieties and breeding lines" the sub-plots, with all treatments replicated three times. There were four crop-topping spray treatments - one unsprayed (Nil) and three spray timings, each spray spaced approximately one week apart (see Table 1) from post-flowering onwards. The crop-topping chemical used was Gramoxone® (250 g/L paraquat) at 2 L/ha. The trial was sown on the Wagga Wagga Agricultural Institute in southern NSW.

Table 1. Description, timing and crop stage of the 4 crop-topping treatments at Wagga Wagga in 2014.

Treatment	Date	Crop timing of the spray
Nil	Unsprayed control	
Early spray	14 October	A week after most pulse varieties had completed flowering
Mid spray	22 October	Approximately one week before physiological maturity of the earliest finishing pulse variety
Late spray	29 October	After the earliest varieties had reached harvest maturity

The pulse treatments included 16 field pea breeding lines and varieties, one faba bean line and one lentil variety. Ten of the field pea lines, sourced from previous PBA breeding experiments conducted at Wagga Wagga, were selected for early maturity and high yield. The six commercial field pea entries were recent releases and similarly varied widely in maturity. The faba bean breeding line was AFO7175 - reputedly early flowering with early maturity. PBA Hurricane XT is a high yielding imidazolinone tolerant lentil variety.

The dates of crop development, flowering and maturity were recorded on a bi-weekly basis from the first replication of the Nil treatment, as only minor variation was observed across replicates for the same variety. Date of start of flowering was recorded when 20% of plants had their first flower open. Date of end of flowering was recorded when 95% of plants finished flowering (flowers closed, dropped off or desiccated). Date of crop maturity was recorded when all plants had turned brown, ripe and judged ready for mechanical harvest.

The trial was conducted under weed-free conditions using current recommended management and cultural practices. Glyphosate (1.5 L/ha) + Goal® (75ml/ha) were used pre-sowing to control weeds and Terbyne ® (1kg/ha) + Stomp® (2L/ha) were incorporated by sowing for post sowing residual weed control.

Results

The season was characterized by above average early season rainfall (April to July) which recharged soil moisture profiles, but was followed by a very dry and warm July to October period (rainfall 50% below average and mean daily temperatures 2° C above average). Flowering dates reflected normal variety patterns for this area but the dry warm finish hastened the end of flowering and maturity by about 2-3 weeks.

Dates of flowering and maturity of all pulse varieties and breeding lines are presented in Table 2. These dates reflect a wide variation in development stages across variety and breeding lines. Start of flowering varied by up to 28 days across entries but this gap reduced to only 7 days by the end of flowering and 12 days by maturity.

The first crop-topping spray application (14 October) was far too early for all pulse genotypes and yield losses were substantial, ranging from 42-82%. The majority of this yield loss was attributed to reductions in seed size (measured as grams per 100 seeds, ranging from 30-63 %). The commercial variety SW Celine and four breeding lines were least affected at this spray but Kaspa field pea and lentil suffered considerably greater losses. Most genotypes showed no significant yield losses at the last two spray applications (22 and 29 October), suggesting physiological maturity had been reached. Exceptions were PBA Percy, Kaspa, OZP1415, faba bean and lentil, all of which showed consistent yield losses of 11-21% at the second spray and 4-11% at the final spray.

Table 2. Dates of flowering and maturity of 16 field pea varieties and breeding lines, one faba bean variety and one lentil variety when sown on 7 June 2014 at Wagga Wagga NSW.

Variety	Start Flowering	End Flowering	Length of Flowering - days	Crop Maturity
PBA Percy	7 Sep	10 Oct	33	4 Nov
Celine	13 Sep	8 Oct	26	30 Oct
PBA Oura	14 Sep	8 Oct	24	31 Oct
PBA Pearl	17 Sep	10 Oct	23	2 Nov
PBA Wharton	22 Sep	10 Oct	18	2 Nov
Kaspa	27 Sep	10 Oct	13	5 Nov
07H082P005	8 Sep	10 Oct	33	27 Oct
06H461P-4	12 Sep	10 Oct	28	29 Oct
07H467P004	12 Sep	8 Oct	26	29 Oct
08H226-HO09-2	12 Sep	9 Oct	27	29 Oct
07H119P002	13 Sep	10 Oct	27	29 Oct
06H445P-5	13 Sep	8 Oct	25	30 Oct
08H019-HO09-12	15 Sep	8 Oct	24	31 Oct
06H204P-10	15 Sep	9 Oct	24	2 Nov
OZP1415	16 Sep	12 Oct	27	4 Nov
05H278-06HOS2003	23 Sep	8 Oct	15	2 Nov
Faba bean (AFO7125)	31 Aug	8 Oct	38	5 Nov
Lentil (PBA Hurricane XT)	13 Sep	15 Oct	32	8 Nov

Table 3. Grain yield comparisons of 18 pulse varieties and breeding lines allowed to mature naturally (nil spray) compared to crop-topping on 14, 22 and 29 October 2014.

Variety	Grain Yield t/ha				% Yield Loss		
	Nil	14 Oct	22 Oct	29 Oct	14 Oct	22 Oct	29 Oct
SW Celine	2.39	1.35	2.30	2.40	43	4	-1
PBA Percy	2.06	1.05	1.62	1.90	49	21	8
PBA Pearl	2.04	0.96	1.88	2.11	53	8	-4
PBA Oura	2.14	0.98	2.02	2.11	54	6	2
PBA Wharton	2.08	0.75	1.89	2.23	64	9	-7
Kaspa	1.65	0.30	1.39	1.69	82	16	-2
07H082P005	2.13	1.24	2.15	2.28	42	-1	-7
06H445P-5	1.97	1.14	1.97	2.16	42	0	-10
07H119P002	2.03	1.17	2.02	2.14	43	1	-5
07H467P004	1.95	1.11	1.81	1.99	43	7	-2
08H019-HO09-12	1.97	1.03	2.00	2.07	48	-1	-5
06H204P-10	2.27	1.17	2.14	2.43	49	6	-7
08H226-HO09-2	1.87	0.95	1.73	1.89	49	8	-1
06H461P-4	2.11	1.05	2.03	2.28	50	4	-8
05H278-06HOS2003	2.24	1.02	2.07	2.35	55	8	-5
OZP1415	1.89	0.71	1.69	1.99	63	11	-5
Faba bean (AFO7125)	1.74	0.91	1.58	1.55	48	9	11
Lentil (PBA Hurricane XT)	1.56	0.49	1.30	1.49	69	17	4
LSD (P<0.05)	0.190						

Discussion and Conclusions

Our R&D priority for pulses at Wagga Wagga is to demonstrate they can be a reliable and strong component of southern NSW farming systems and ensure they are a viable and profitable phase of crop sequences. Significant advances in varieties have been made by PBA over the past two decades and this has been complemented by well formulated agronomy packages by state agencies, GRDC and agribusiness. However, tight weed control and reductions in the soil weed seed bank in the pulse phase still remains a priority. Crop-topping fits well here, giving pulse farmers a useful weed control strategy to ensure effective management of weeds that may escape conventional control methods.

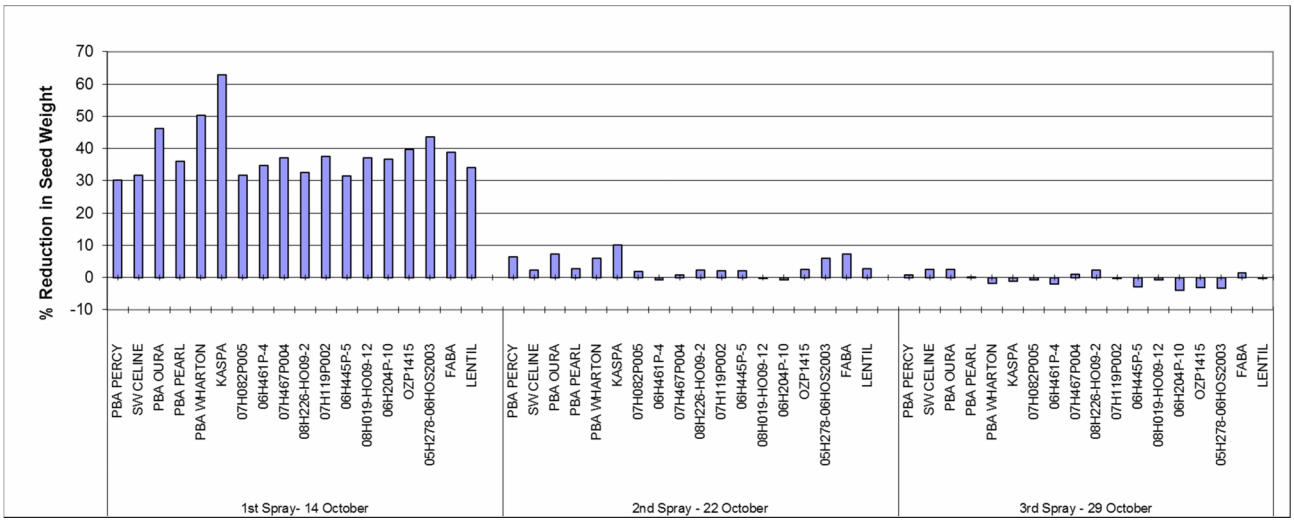

Figure 1. The reduction in seed size of eighteen pulse varieties and breeding lines at Wagga Wagga NSW resulting from three crop-topping sprays on 14 October, 22 October and 29 October 2014.

Field pea was the highest yielding, earliest maturing and best adapted pulse to crop topping within the scope and confines of this experiment at Wagga Wagga in southern NSW. SW Celine was the highest yielding, earliest maturing and best crop-topping treatment. Its yield and seed size was the least affected by the earliest spray (14 October) and unaffected by the last two sprays (22 and 29 Oct). Of the remaining commercial varieties, those best suited to crop-topping were PBA Oura, PBA Pearl and PBA Wharton. Several pea breeding lines also show promise, particularly 07H028P005.

SW Celine is a European bred variety released in Australia 2005 and currently licensed to Nuseed (Anon 2005). It is a semi-dwarf, erect, semi leafless white flowered pea with large, round, creamy-white seeds. Its main feature is its early flowering, early maturity and superior pod set, giving it excellent drought tolerance and yield advantage in dry, quick finishing springs. Unfortunately, the variety does not have the sugar pod type shatter resistance of commercial varieties such as Kaspa, but this feature (as well as other attributes such as disease resistance), could be incorporated through conventional breeding programs in future

Yield and seed size of lentil and faba bean were generally more affected by crop topping than field pea. Only one variety of each was trialled here and future investigations should widen this selection to include earlier flowering and earlier maturing genotypes for different pulse species. Selection of earlier maturing, high yielding pulse varieties suited to crop topping is identified as a valuable breeding objective for southern NSW.

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The effect of crop rotations on the incidence of crown rot in wheat

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Abstract
The crown rot fungus, *Fusarium pseudograminearum*, is a stubble-borne pathogen. Crop rotations are commonly used by farmers to manage the crown rot disease and inoculum survival. However, it is not clear if a preceding rotation crop of wheat, Indian mustard, canola or chickpea reduces the inoculum level and incidence of crown rot in wheat in northern NSW. Four rotation crop treatments with four replicates were established in a greenhouse, inoculated with crown rot fungus and grown for two months. Three wheat genotypes with differing levels of susceptibility were then sown into the same pots with the respective rotation crop residues. The severity of the crown rot disease was scored on six occasions throughout the growing season and the crop yield assessed. In addition, twenty field plots were sown to four rotation crops and a fallow with four replicates at Narrabri in northern NSW. The level of crown rot inoculum was measured at the beginning of the season, after sowing and again after 5 months of wheat growth. Genetic differences in tolerance to crown rot were observed among the three wheat genotypes. In the field, the canola, chickpea and Indian mustard rotation crops reduced the amount of stubble and crown rot inoculum significantly compared with the fallow treatment. *Brassica* and legume crop species may provide an effective crop rotation for the breakdown of crown rot inoculum throughout the growing season.

Key words
Crown rot, crop rotation, fallow, straw decomposition

Introduction
The crown rot disease, caused by the fungal pathogen *Fusarium pseudograminearum*, is a stubble-borne pathogen which detrimentally impacts wheat production in Australia and many other countries (Backhouse *et al*. 2004).Conservation agricultural systems if based on wheat monocultures facilitate the spread of the crown rot disease through no-till farming and the maintenance of ground cover, which often includes the retention of stubble from previous crops. Crown rot restricts wheat production in many areas and can cause losses of up to A$56 million per year in Australia (Kirkegaard *et al*. 2004). The crown rot inoculum can survive for up to two years on infected stubble (Chakraborty *et al*. 2006). This disease has the potential to reduce grain yields by up to 100%, depending on the environmental conditions and the cereal cultivar. As a result, crop rotations are the most common management tool used to combat the crown rot disease, as there are no fully resistant wheat varieties and no chemical control methods currently available (Chakraborty *et al*. 2006). However, whilst the impact of crown rot on cereal crops is widely documented, there is limited research on the effect of the preceding crop rotation on the incidence of crown rot in wheat and the breakdown of the crown rot inoculum. This research tests the hypothesis that the inoculum levels of crown rot will be reduced following chickpea, canola and Indian mustard rotation crops.

Materials and methods
Experiment 1 (Cobbitty)
Experiment 1 was a greenhouse pot experiment arranged in a factorial design with eight replicates conducted in a microclimate room at the University of Sydney Plant Breeding Institute at Cobbitty, NSW. Four rotation crops (Batavia and Suntop wheat, Indian mustard and Desi chickpea) were first planted in the pots followed by two bread wheat varieties and one durum variety: Bellaroi (a very susceptible durum cultivar), Batavia (susceptible bread wheat) and Suntop (moderately resistant bread wheat). The rotation crops were planted on 16 April 2014 and inoculated with crown rot two weeks after planting. Discs (5 mm diameter) of fungal mycelium were cut out of fungal cultures grown on potato dextrose agar and placed in the middle of eight seedlings in each pot, covered with wheat bran and watered. The rotation crops were left to grow for six weeks and harvested, leaving 3 cm of stubble. The following wheat crops were planted into the residual stubble on 19 June 2014. The plants in each pot were scoredsix times at fortnightly intervals using the 0 to

4 crown rot scoring system based on stem basal browning (Table 1). Heads were harvested on 3 September 2014.

Table 1. Description of the different crown rot scores used in experiment 1.

Score	Description
0	No lesions produced by the crown rot infection
1	First internode is partially lesioned
2	First internode is fully lesioned and there are partial or full lesions on the second internode
3	Partial or full lesions are present on more than two internodes
4	White head produced as a result of the crown rot infection

Experiment 2 (Narrabri)

Experiment 2 was a field experiment conducted on a field with high levels of crown rot inoculum (block D1B) at the I.A. Watson International Grains Research Centre, located 10 km north of Narrabri (30.3167oS, 149.7667oE and 212 m elevation). In 2013 this block was sown to a range of wheat varieties to encourage the build-up of crown rot inoculum. On 12 May2014, twenty plots (6 m x 2 m) were sown to Suntop wheat, Indian mustard, canola, chickpea or left fallow with four replicates in a randomised complete block layout. Narrabri has a subtropical semi-arid climate, with a mean average maximum temperature of 34oC and an average minimum temperature of 4oC, a summer dominant rainfall pattern with an average annual rainfall of 659 mm. The soil type in block D1B is a self-mulching, grey Vertosol. Samples of stubble and soil were collected twice; on 26 June and 1 September 2014. These samples were assessed using the PreDicta B soil test to detect soil borne pathogens using DNA analysis to give an indication of the amount of crown rot inoculum in the field. Five random samples were taken from each plot and sent to the South Australian Research and Development Institute (SARDI) for analysis. Stubble was sampled using a square metre quadrat in each plot, dried in a dehydrator (80°C for 12 h) and weighed. Eleven humidity and temperature data loggers were inserted into ten of the plots to measure relative humidity and temperature from 12 September 2014. Analyses of variance (ANOVA) and repeated measures analyses were conducted using Genstat 16th Edition.

Results and discussion

Experiment 1 (Cobbitty)

Bellaroi produced the highest crown rot scores with an average score of 3.6 at 94 days after planting (Fig. 1). Suntop produced the lowest average score of 2.5, while Batavia was rated moderately susceptible with an average score of 2.9(Fig. 1).The percentage of infected plants increased dramatically over the first three observations, reaching 100% infection across all treatments at the fourth observation (data not presented). This is consistent with the literature showing the relative susceptibility of Bellaroi durum and tolerance of Suntop to crown rot (Al-Fahdawi et al. 2014).

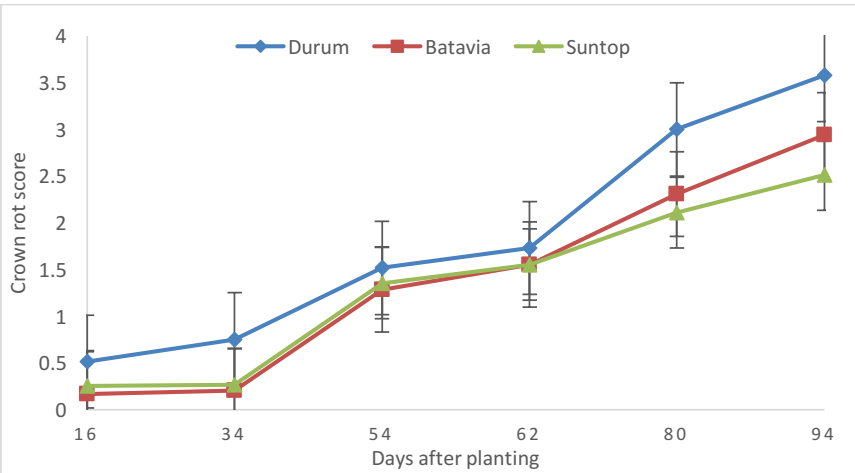

Fig. 1. Effect of wheat variety (Bellaroi, Batavia and Suntop) on the crown rot disease score (0-4). The LSD (p=0.05) were 0.28 at 80, and 0.23 at 94 days after planting, respectively. Error bars represent +/- one standard error of the mean.

The rotation crops produced no significant interaction with the following wheat genotype(*P=0.586*) under crown rot infection (data not presented).The inoculation applied to each pot fostered the growth of the *Fusarium pseudograminearum* and these high levels of inoculum may not have been broken down by the rotation crops within the 6 week period prior to the wheat sowing. This method could be improved by the removal of the wheat bran which was used to foster the growth of the fungus and contains the majority of the crown rot inoculum.

Rotation crops had a significant effect on the breakdown of crown rot inoculum, compared with fallow conditions in experiment 2 (Fig. 2). The percentage stubble reduction ($P<0.001$, 31%) and the percentage PreDicta B reduction ($P=0.043$, 36%) was greatest under the canola treatments and lowest under fallow (Fig. 2). The three rotation crops (canola, chickpea and Indian mustard) decreased the amount of stubble and crown rot inoculum compared with the fallow treatment.

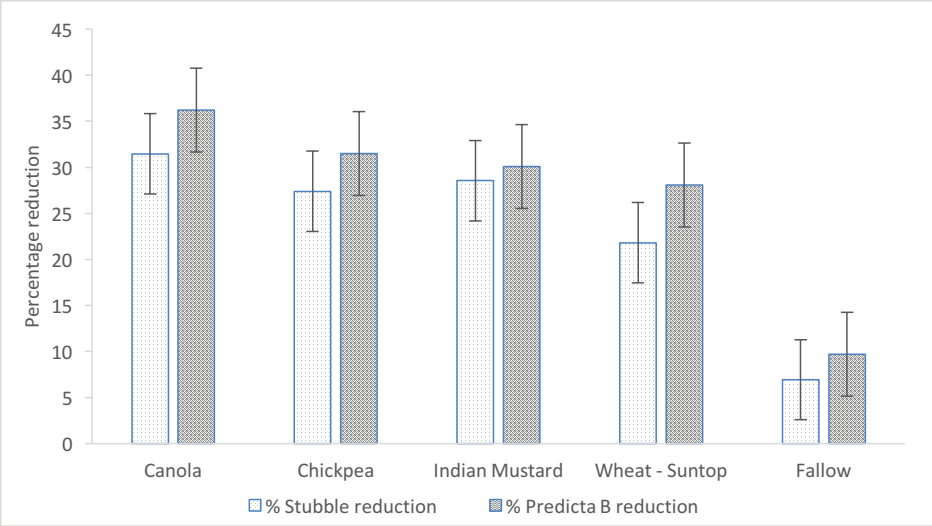

Fig. 2. Effect of crop rotations (canola, chickpea, Indian mustard, Suntop and fallow) on the reduction of stubble levels (dotted) and PreDicta B (hashed) values. LSD (p=0.05) were 2.6 for stubble reduction and 15.6 for PreDicta B reduction. Error bars represent +/- one standard error of the mean.

The high relative humidity and stable temperatures (data not presented) under the various rotation crops possibly helped establish a microclimate conducive to the breakdown of previous wheat stubble and crown rot inoculum; an observation supported by other studies (Kirkegaard *et al*. 2004; Evans *et al*. 2010). Models have been developed to demonstrate stubble decomposition and the effect of the environment on decomposition (Lakhesar *et al*. 2010; Backhouse 2014). Most of these models assume that inoculum breakdown can be represented as an exponential decay function and incorporate indices to account for moisture availability and temperature, or thermal time (degree-days) adjusted for rainfall (Lakhesar *et al*. 2010). However, these models only consider moisture that comes from rain or dew and do not consider soil moisture or the moisture content of stubble. Further refinement of these models will provide improved predictions through the incorporation of rainfall, crop biomass, temperature fluctuation, available moisture other than rainfall and dew and the severity of the crown rot infections (Lakhesar *et al*. 2010; Backhouse 2014).

Chickpea has the ability to fix nitrogen through a symbiotic relationship with rhizobium bacteria. However the ability of legume crop species to fix nitrogen may not aid the suppression of the crown rot disease. Previous studies showed that the increased soil nitrogen produced by chickpea can exacerbate the severity of crown rot in the following wheat crop (Kirkegaard *et al*. 2004; Chakraborty *et al*. 2006). Chickpea also produces malic acid in the leaves, although this is unlikely to restrict grain production as the majority of the leaves were removed when the rotation crops were harvested (Chakraborty *et al*. 2006). Canola and Indian mustard produce glucosinolates which potentially have biofumigation effects on the soil environment (Gimsing and Kirkegaard 2009; Bohnic *et al*. 2012).The glucosinolates released into the soil may restrict the growth and production of the following wheat crop when crop residues do not have sufficient time to break

down. In field conditions, the canola or Indian mustard crop would be produced one year and the wheat crop produced in the second year. This would allow the crop residues and glucosinolates to break down to non-inhibitory levels. *Brassica* crop species, such as canola and Indian mustard, are not susceptible to the crown rot pathogen and are therefore ideal for breaking the disease cycle (Halkier and Gershenzon 2006).

Conclusions

This study showed that crop rotations can reduce the incidence of crown rot in field grown wheat. Rotation crops encouraged stubble breakdown more than fallow, which led to a reduction in the amount of crown rot inoculum. *Brassica* and legume crop species may provide an effective crop rotation for the breakdown of crown rot inoculum throughout the growing season.

Acknowledgement

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Improved early wheat growth after millet and cowpea in the central cropping belt of Western Australia

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Abstract
A four year field experiment commenced at Meckering, Western Australia, in October 2013, to evaluate the potential of a summer active C4 sub-tropical grass, millet, and a C3 sub-tropical legume, cowpeas, as cover/break crops to improve wheat growth and yields. In the first season (2013/14) the summer crops were sown on the 25th October after a wet spring period and the harvest of a hay crop, then managed as short or long-season cover crops before herbicide was applied to terminate their growth. Treatments with summer crops were compared with no summer crop, where weeds were either controlled with herbicides or left unmanaged. Above ground summer biomass production was low (<0.5 t/ha) as a consequence of one of the driest summers on record. With less than 10mm of in-crop rainfall over summer, the crops were nonetheless able to survive on stored soil moisture until herbicides were applied. Despite additional water and nitrogen use compared to fallow, all of the summer crop treatments had a similar, positive effect on the early growth of the following wheat crops. Wheat biomass at tillering was 26% (0.17 t/ha) higher on average after summer crops than after summer chemical fallow. Improved early growth didn't result in higher grain yields, possibly because of below average winter rainfall and a higher presence of pythium root rot in the soil compared with the chemical fallow.

Key words
Wheat yield, summer active, break crops, disease.

Introduction
It is well documented that crops sown into their own residues can yield less than crops that are sown into the residues of another 'break' crop species (Malik et al., 2015). Yet, crop rotations include successive wheat crops in the central cropping belt of Western Australia because wheat is considered the most reliable and profitable crop. There is widespread recognition amongst farmers that the sustainability of cropping systems could be improved through the inclusion of alternative crops in rotation with cereals (Carmody and Prichard, 2009). However, break crops remain underused (Robertson et al., 2010; Seymour et al., 2012), with benefits that are variable (Lawes et al., 2013) and opportunity costs from replacing higher value cereal crops that can be too high. One option to increase the number of break crops in rotations that has been given little attention is to replace a summer fallow with a summer-active crop species i.e. when the opportunity cost of growing a break crop is comparatively low. This tactic has largely been disregarded because of the difficulties of establishing summer crops with low and variable rainfall, low yield potential, and the potential consequences of summer growth depleting stored soil water before a winter crop. Such challenges might be overcome with different management strategies should it first be demonstrated that low yielding summer crops can increase the yields of following wheat crops. This paper reports results from the first year of a four-year experiment comparing the observed impacts of a chemical fallow, millet or cowpea summer crops on the following wheat crop.

Materials and methods
Site, soil and treatments
A field experiment commenced in 2013 at Meenaar (116°86´E, 31°62´S) in the central cropping zone of south-east Western Australia. The site had been previously cropped with wheat in 2011, canola in 2012 and wheat in 2013. Average annual rainfall at Meenaar is 382mm with ~80% received from May and October, which is the winter growing season. The duplex type soil was sandy on top with 59g/kg clay increasing to159g/kg clay in the subsoil layers (10-30cm). Wheat was sown into four randomised summer treatments, each replicated four times. These were:

1. chemical fallow (weeds controlled with herbicides as early as possible);
2. weedy fallow (herbicides applied to kill weeds 21 weeks after treatments commenced);
3. millet (*Panicum miliaceum*) killed with herbicides after 16 weeks; and
4. cowpea (*Vigna unguiculata*) or millet killed with herbicides after 21 weeks.

Main field activities

The site was prepared on 24 October 2013. The wheat growing at the site was cut for hay and weeds were sprayed with 1140g ai/ha of the broad spectrum herbicide glyphosate (Roundup Ultramax®570 g/L). Millet and cowpeas were sown into wet soil (7.31% v/v) the following day with no-tillage knife-points on 0.22m row spacing at a seed rate of 8kg/ha and 11kg/ha, respectively. The cowpea seed was treated with a peat based Group I innoculant (Nodulaid®) on the day that the summer crops were sown. Superphosphate fertiliser was applied with the seed at a rate of 100kg/ha. The summer crop growth was terminated with the same rate of glyphosate, after the specified growth period (i.e. 16 or 21 weeks after sowing). Wheat (cv. Corack) was sown into the treatment plots on the 9th June 2014 with no-tillage knife-points on 0.22m row spacing. The sowing rate was 75kg/ha with 80kg/ha NPKS fertiliser (10.2% N, 13.1% P, 12% K, 7.2% S) deep banded below the seed at 10-15 cm. Urea was broadcast at 6 weeks after sowing at 100kg ha^{-1}.

Crop biomass, litter estimates and grain yields

'Out of season' biomass (summer crops etc.) was estimated from 1-4 April and growing season biomass from 3-6 August at the wheat tillering crop growth stage (Z18, 13 wks). A rapid, visual assessment technique (Tothill et al., 1992) was used to estimate separately the components of above ground biomass (total crop biomass, weed biomass and soil surface residues) in each treatment plot. For calibration, the weights from 40 crop cuts (two crop cuts were taken per treatment plot) were plotted against the visual estimates (40 fixed observation points spaced 1m apart along a diagonal transect in each plot) such that regression (linear mixed model) results were used to convert visual estimates into biomass values (Genstat V17, April Adj. $R^2 = 0.70$, August Adj. $R^2 = 0.82$). Grain was harvested with a small plot header over the full length of the each treatment plot (40m) and dried to a constant weight. A subsample of grain from each treatment plot was analysed for grain protein and screenings.

Soil water and nitrogen

Soil cores 40 mm in diameter were sampled from each treatment plot in April after all the summer crops had been killed with herbicides. The cores were collected in 10cm increments to a depth of 50cm with an electrically driven auger bit and vacuum to suck the disturbed soil into a sample collection bucket (Andrew and Gazey, 2010)Western Australia</title><secondary-title>19th World Congress of Soil Science</secondary-title></titles><dates><year>2010</year><pub-dates><date>1-6 August 2010</date></pub-dates></dates><pub-location>1-6 August, Brisbane, Australia</pub-location><urls></urls></record></Cite></EndNote>. Eight soil cores were collected from each depth and bulked together. The wet and dry weight of the soil and the bulk density were used to calculate the total volumetric soil water content. Crop available soil water was calculated as the amount of water above the crop lower limit measured at the site (Dalgliesh and Foale, 1998).

Soil pathogens

Five soil samples (0-5cm) were taken from the start and end of each treatment plot when wheat was tillering and flowering. The soil from each location was bulked together and submitted to the Predicta B® root disease testing service for analysis of soilborne disease innoculum. Data were analysed with a linear mixed model (Genstat v.17) following transformation (log_{10}).

Results

Rainfall

There was above average spring rainfall prior to sowing the summer crops in late October 2013. There was then only 12.5mm of out of season rainfall which is well below the long term average of 61mm. Autumn rainfall (115mm) was above average, prior to sowing the 2014 wheat crop in early June. The wheat crops then received 157mm of rainfall from June through to August, which was 43mm less than the long term average rainfall for that winter period. Late growing season rainfall (Sept-Nov) was 76mm which is about average for the region.

Soil water, nitrogen and wheat residue cover following summer crops
Available soil water and nitrogen (mm, $NH_4^+ + NO_3^-$, 0-50cm) in April was highest in the chemical fallow (14mm, 31kg N/ha) followed by millet (16/wks growth) and weedy fallow (11-12mm, 26-28kg N/ha), cowpea and millet killed after 21 weeks growth (4-7mm, 18-19kg N/ha) (soil water p=0.023, nitrogen p=0.006). The amount of crop residue in the chemical fallow and weedy fallow was similar (2.66t and 2.36t/DM/ha respectively). This was higher than the amount of crop residue observed in the summer crops treatments (p=0.008). The lowest residue amount was after cowpea which had 1.1t/DM/ha. The two millet treatments were similar with 1.4t and 1.7t/DM/ha. The amount of crop residue was not related to differences in summer crop biomass production which was low (<0.05t/DM/ha) in all of the treatments.

Wheat yields and presence of soil pathogens
Wheat biomass at tillering was 26% higher on average in the summer crop treatments compared to the chemical fallow treatment and there was no effect of type of summer crop or its duration (Figure 2a). The trend for higher growth after summer crops was evident at flowering but wasn't significant (data not shown). Wheat grain yields (~2.3t/ha) and protein (~10.3%) were similar in all treatments, with higher screenings in the weedy fallow (5.4%) compared with summer crops (4.8%) and chemical fallow (4.3%) (p=0.044, l.s.d = 0.77).

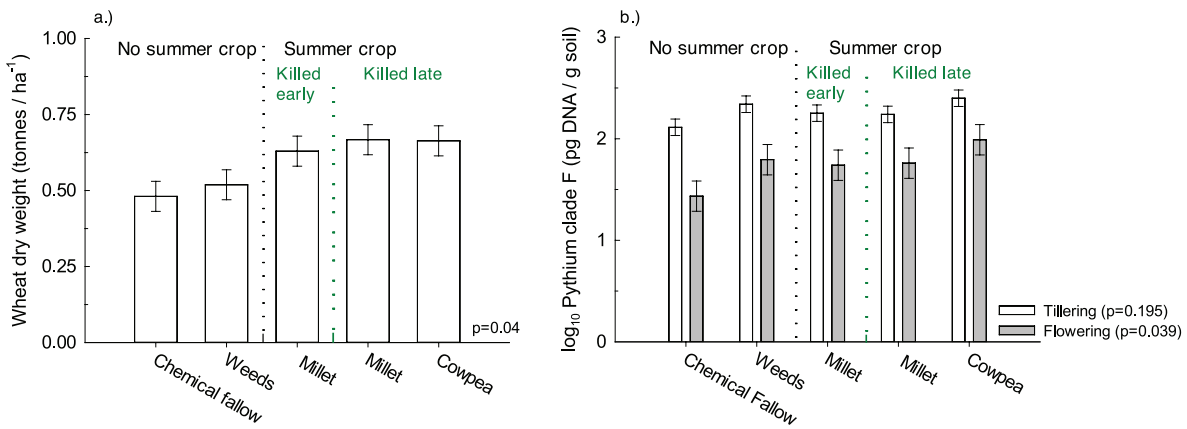

Figure 2. a) Wheat biomass at tillering in the treatments on the 6th August, b) Predicta B levels of pythium root rot at the wheat tillering and flowering crop growth stages. Error bars are the mean standard error of the estimates.

Common soil pathogens at the site were below the detection limit. However, there was evidence of higher presence of pythium root rot (Pythium clade F) at wheat flowering in the summer crop treatments compared with chemical fallow (Figure 2b). The weedy fallow also had higher levels of root rot detected than chemical fallow.

Discussion

There was an early break crop effect in the following cereal crop when preceded by summer crops. The benefit for early wheat growth (+26%) was higher than the early growth benefits in wheat reported in another study (Kirkegaard et al., 1994) that compared wheat growth after Brassica break crops. In the latter study, a 14-15% average increase in shoot biomass was observed at wheat stem elongation following winter break crops. There was up to 60% less crop residue (mainly wheat) present at the soil surface in autumn after summer crops as a result of incorporation of old wheat residue at summer sowing and perhaps a faster rate of decomposition. On the one hand, the lesser amount of residue implies a reduction in the source of innoculum for leaf diseases and less early infection of the leaves of wheat seedlings after rainfall (Krupinsky et al., 2007). However, wheat residue incorporated in the soil with summer sowing, and perhaps the living plants, appears to have hosted higher levels of pythium root rot in the soil compared to chemical fallow. This combination of disease impacts might explain why the early growth benefits for wheat following summer crops weren't sustained and didn't translate into higher grain yields. However, the benefits for wheat after a break crop are often evident at an early growth stage but improved early growth doesn't always result in higher grain yields (Kirkegaard et al., 2008). Therefore, low available soil water after below average rainfall in winter might have been the dominant factor preventing the better growing wheat crops achieving

their higher yield potential. The results suggest that an integrated management approach will be required to achieve a wheat yield increase in rotations with the inclusion of a summer break crop. Aspects that farmers might consider are the rotation with summer crops (e.g. alternative cereals like oats and barley), residue management at winter harvest (cutting height and spread), the level of soil disturbance at sowing times, weed/disease host control within summer crops and the use of cereal fungicide options (Malik et al., 2015) to suppress soil-borne disease.

Conclusions

There was evidence to conclude that summer crops can provide a break effect for following crops. However, it is too early to conclude whether summer break crops have a fit in crop rotations dominated by winter cereals. Both soil water availability and crop residue management may have impacted wheat crops reaching their higher yield potential. The effects of these aspects need to be separated in future research.

Acknowledgements

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Effects of sprinkler irrigation during the flowering period on flower development and pyrethrin accumulation in Pyrethrum

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Abstract
Pyrethrum (*Tanacetum cinerariifolium*) is an economically important perennial crop grown for extraction of the natural insecticide pyrethrin, which accumulates in the achenes of the flower heads. Pyrethrum is a comparatively drought tolerant plant due to deep rooting and rarely shows visual symptoms of water deficit, even when exposed to high water deficit conditions in late spring and early summer in the pyrethrum growing regions of Australia; however irrigation is still needed during the post flowering period, when pyrethrin is synthesized, to alleviate water deficit and to obtain substantial yield benefits. This experiment was conducted in a first harvest commercial pyrethrum field in Waubra, Victoria, during the 2012/2013 season to understand the effects of sprinkler irrigation applications during the flowering period on flower development and pyrethrin accumulation. The results of this experiment showed that the application of irrigation throughout the flowering period, significantly increased total pyrethrin concentration by 19%, which combined with a 60% increase in flower yield to give a pyrethrin yield increase of 91%, compared to the rainfed treatment. Irrigation treatments applied throughout the flowering period significantly increased flower yield as a result of enhancement in flower number and flower size. Overall, irrigation provides adequate soil moisture for flower development which slows the rate of flower development and increases the duration of the flowering period, resulting in higher pyrethrin yield at physiological maturity. The findings of this study will be important for future yield predictions and to develop advanced agronomic strategies to maximize pyrethrin yield in pyrethrum.

Key words
Perennial crop, water deficit, achene, physiological maturity

Introduction
Pyrethrum (Tanacetum cinerariifolium (Trev.) Schultz Bip.) is an economically important perennial crop belonging to the family Asteraceae, commercially grown for extraction of a group of potent insecticidal secondary metabolites collectively called pyrethrins from the achenes of its flower heads (Bhat and Menary, 1984; Grdisa *et al*., 2009; Casida and Quistad, 1995). Most (93.7 %) of the pyrethrin is derived from the achenes of mature pyrethrum flowers (Chandler, 1951). Relative to flower dry weight, achenes contain approximately 1.8–2.5% pyrethrins (Bhat and Menary, 1984; Fulton, 2001).

There is considerable demand worldwide for pyrethrins as a natural insecticide to avoid excessive use of synthetic insecticides (Grdisa *et al*., 2009; Krieger, 2001). Pyrethrum production in Australia currently supplies more than 70% of the global market requirements, for which the production areas are predominantly centered on the North West coast of Tasmania and in the Ballarat region of Victoria. Pyrethrins exist as a combination of six esters; pyrethrin I, cinerin I, jasmolin I, and pyrethrin II, cinerin II and jasmolin II, with pyrethrins I and II present in higher concentrations (Head, 1966; Crombie, 1995). A typical extract contains the pyrethrins, cinerins and jasmolins in the proportion 10:3:1 with the ratio of pyrethrin I to pyrethrin II (PyI:PyII) typically around 1:1. Pyrethrin I, cinerin I, jasmolin I are collectively 'pyrethrins I' and pyrethrin II, cinerin II and jasmolin II are collectively 'pyrethrins II'(Crombie, 1995).

Irrigation management has been identified as an area of crop management that could be manipulated to increase yield. Previous studies have indicated that low moisture availability during flower development may reduce the accumulation of pyrethrins (Mohandass and Sampath, 1986). Irrigation during a water deficit

period is essential to achieve potential yield. Under dry conditions, irrigation results in an overall increase in the rate of water uptake and growth of crop plants. Pyrethrum is a comparatively drought tolerant plant and it has some ability to survive in dry conditions due to deep rooting. This facilitates the extraction of water from as deep as one meter in the soil profile (Salardini *et al*., 1998). Pyrethrum plants rarely show visual symptoms of water deficit, even when they are exposed to high moisture stress conditions in late spring and early summer in the pyrethrum growing regions of Australia, but irrigation is still needed during the flowering period, when pyrethrins are synthesized in the flower heads, to prevent water deficit and to obtain substantial yield benefits. Pyrethrum cannot reach its full yield potential under water deficit conditions (Chung *et al*., 1991).

Materials and Methods

Experimental setup and treatments

This experiment was conducted in a first harvest commercial pyrethrum field in Waubra, Victoria, Australia during the 2012/2013 season to investigate the effects of irrigation on flower development and pyrethrin accumulation. Treatments were applied as 'rainfed' and irrigated for the whole flowering period by establishing a sprinkler irrigation system. All other commercial agronomic practices such as application of fungicides, fertilizers, herbicides and growth regulators were similarly applied to both treatments. Four replicate plots (3 m x 3 m in size with sprinklers in each of the corners) for each treatment were established in a randomized block design. Irrigation treatment plots were irrigated up to 20 mm each time in order to replace the 20 mm deficit. Microclimatic conditions including temperature, rainfall, solar radiation, wind speed, wind direction and barometric pressure were recorded at each 5 minutes by the onsite weather station (IC6328AU Wireless Vantage Pro2™ Plus, Davis, California, USA). Soil moisture tension was monitored continuously every 15 minutes using gypsum block tensiometers (MEA Bug system, Magill, South Australia) with the measurement range from 0 to 200 kPa, buried at 30 cm and 60cm depths in one replicate plot of each treatment. Irrigation timing and water levels were scheduled using the rainfall data, evapotranspiration data, previously recorded crop factor data and soil moisture depletion data. Irrigation applications were started (day 1) when flowers reached flower maturity stage 1(fully developed buds) and continued to maintain the soil moisture tension at 30cm soil depth below 70 kPa (O'Donnell, 2001) and continued until flowers starting to dry off. Sampling was undertaken once a week from all eight plots, until all plots reached the physiological maturity stage (approximate flower maturity index of 600). One sample per each plot was collected at each sampling date using a randomly positioned 0.5 m^2 quadrant.

Biomass and flower maturity index

Plants contained in each quadrat were harvested, separated into stems and flowers. Flower stage composition was recorded to calculate the flower maturity index (FMI) using the following equation (Potts and Menary 1987). Stems, leaves and flowers samples were oven dried at 60oC and weighed. A representative subsample of flowers from each plot was taken for pyrethrin concentration analysis.

$$\text{Flower Maturity Index} = \frac{\Sigma\,(\text{Flower maturity stage x Number of Flowers})}{\text{Total number of flowers}} \times 100$$

Pyrethrin determination

Extractions were conducted by mixing 0.2 g powdered flower samples with 9.8 ml hexane (Riedel-de-Hahn, Chromasolv grade) three times in 24 h. Two millilitres of the supernatant was filtered (Alltech 13 mm, 0.45_m PTFE syringe filter) and used for further analysis. High-performance liquid chromatography (HPLC) analyses and quantitation were performed as described by McEldowney and Menary, 1988 for pyrethrin analysis. Pyrethrins were chromatographically separated and expressed as percentage total pyrethrins per dry weight of extracted sample.

Statistical analysis

The experimental results were subjected to an analysis of variance (ANOVA) and significantly different means were compared using Tukey's test at 95.0% confidence ($P < 0.05$) using the Minitab 16 (Minitab Inc., Pennsylvania, USA) statistical software.

Results and Discussion

Above ground dry matter production and flower yield

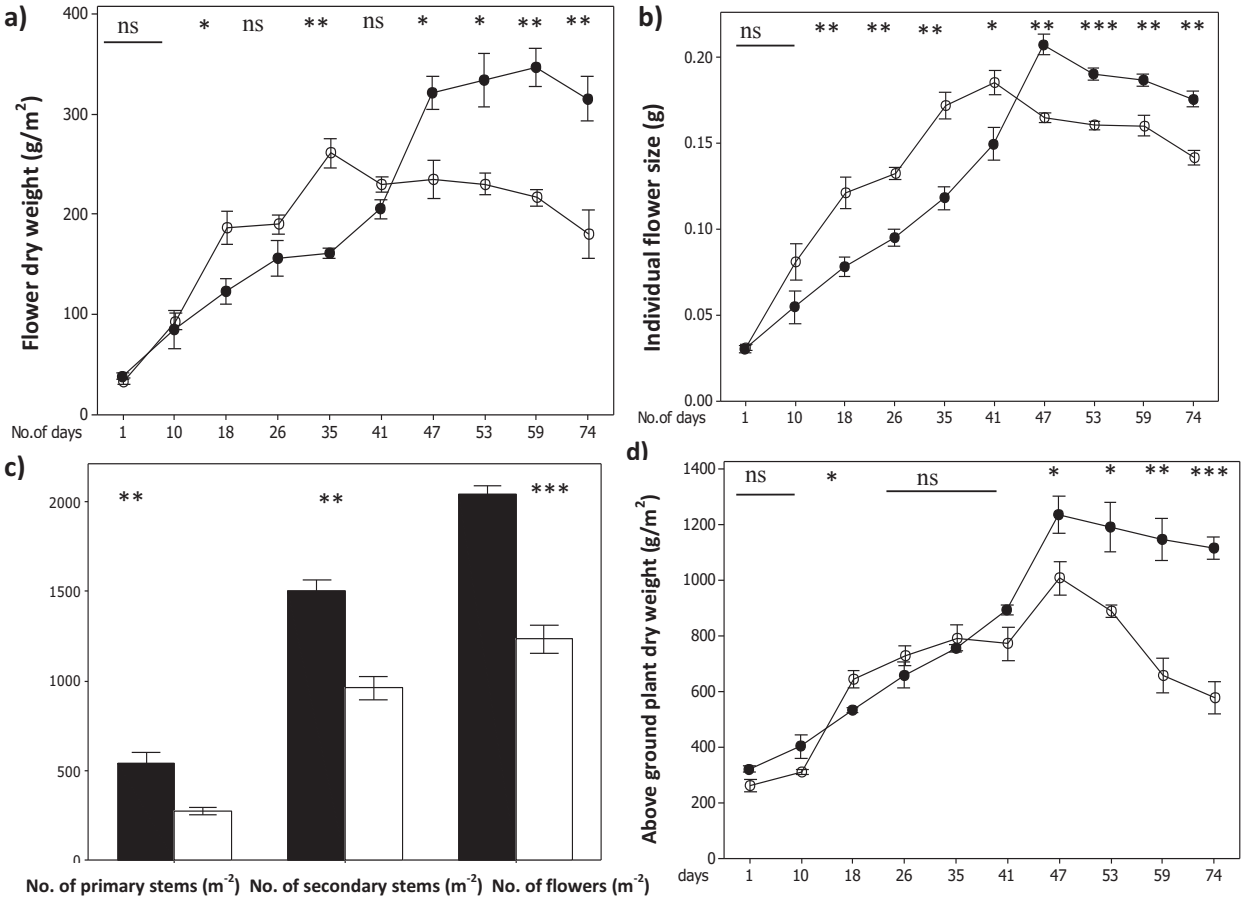

Figure 1: Changes in flower yield and above ground biomass during the flowering period (a; Flower dry weight, b; Individual flower size c; number of stems and number of flowers d; Above ground dry weight. Values are means (±SE) of n=4.●, means for the irrigation treatment, ○, means for the rainfed (non-irrigated) treatment. Abbreviations: ns, not significant (>p.0.05); * p<0.05; ** p<0.01; *** p<0.001

The results of this experiment indicated that 41 to 47 days seems to be a critical period. Before 41 days, flower size increases at a slower rate under irrigation. Irrigation allows an accelerated rate from 41 to 47 days, while the rate decreases in the rainfed treatment. Adequate water supply at late flowering stage seems critical for flower growth (Fig. 1b). The increase in the number of flowers per unit area is attributed to an increase in the number of stems per plant and an increase in the number of flowers per stem. Flower number was significantly greater in the irrigation treatment due to production on significantly higher number of primary and secondary flowering stems compared to rainfed treatment (Figure 1c). The production of primary flowering stems in Pyrethrum is mainly governed by the vernalisation requirement (Brown and Menary, 1994; Casida and Quistad, 1995), therefore the possibility for an increase in number of primary stems by irrigation during flowering is limited. However the results of this experiment indicated that high soil moisture availability in early stages of the flowering period due to the application of irrigation favoured rapid elongation and branching of the primary flowering stems to produce significantly higher number of secondary flowering stems. This eventually led to increased flower number compared to the rainfed treatment. Flower number was highly variable on different sampling days, but greater under irrigation at most of the sampling days compared to the rainfed treatment. Flower yield in the irrigated treatment was lower than the rainfed treatment at early sampling days. As a result of the slow rate of flower development in the irrigation treatment, individual flower size increased slowly at early sampling days, then more rapidly with flower maturity and reached a larger size than in the rainfed treatment. The enhancement of flower yield and number of stems contributed to the significant increase in the total above ground biomass per unit area at later sampling days under irrigation (Figure 1d).

Pyrethrin yield

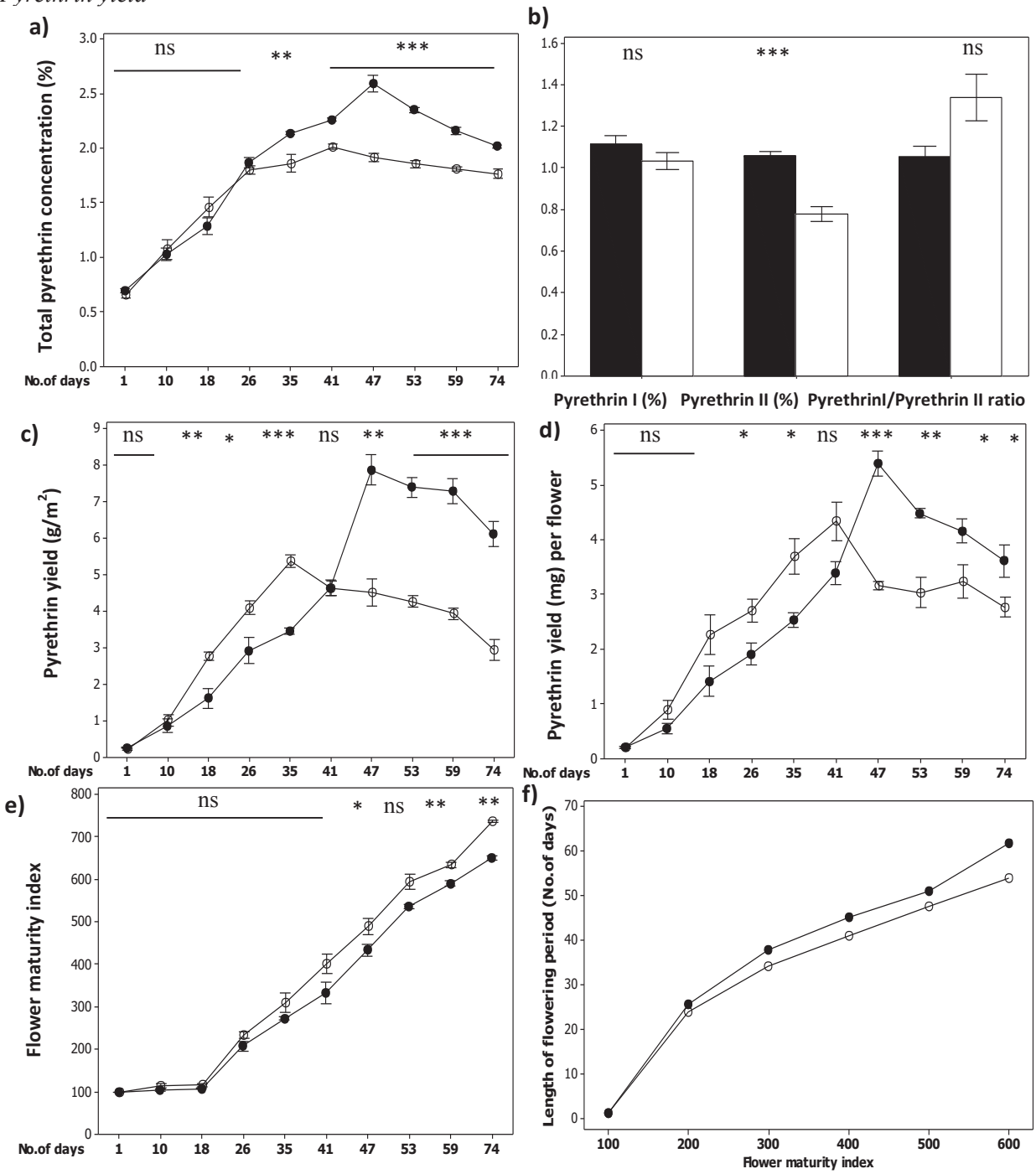

Figure 2: Changes in pyrethrin yield and rate of flower development during the flowering period (a; Total pyre concentration b; Pyrethrin I, Pyrethrin II and Pyrethrin I/ Pyrethrin II ratio c; Total pyrethrin yield per plant Total Pyrethrin yield per flower e; Flower Maturity Index f; Length of flowering period with flower maturity i Values are means (±SE) of n=4. ●, means for the irrigation treatment, ○, means for the rainfed (non-irrigated) treatment. Abbreviations: ns, not significant (>p.0.05); * p<0.05; ** p<0.01; *** p<0.001

The results of this experiment showed that the application of 240 mm of irrigation throughout the post-flowering period, from early flower maturity stages to physiological maturity markedly increased total pyrethrin concentration by 32% (Figure 2a), which combined with a 60% increase in flower yield (Figure 1a) to give an increase in total pyrethrin yield increase of 91% (Figure 2c) at physiological maturity compared to the 'rainfed' treatment. Pyrethrin yield was increased gradually with flower developmental stages in both treatments before declining in the later stages of flowering (Figure 2c). Pyrethrin concentration showed a rapid increase in the early stages followed by a slower increase in the mid flower maturity stages, then a decline at later stages (Figure 2a). The decline occurred at an earlier sampling date in the rainfed treatment

due to more rapid flower development, but the peak pyrethrin concentration was higher under irrigation than in the rainfed treatment. Pyrethrin yield per flower declined at the later stages of flowering (Figure 2d), corresponding to the decline in individual flower size during these stages (Figure 1b). At later stages of flower development, under elevated temperature conditions in mid summer and due to absence of adequate soil moisture, crops rapidly become over-mature and unable to continue pyrethrin accumulation at maximum capacity resulting in a reduction in pyrethrin yield; therefore irrigation of crops at later stages of flower development can slow down the rate of flower development under temporary stress (such as a few days of high temperature) and increase the duration of the flowering period to obtain maximum pyrethrin yield. Both pyrethrin I and pyrethrin II were greater in the irrigation treatment compared to rainfed treatment at physiological maturity (Figure 2b). As flowers approached maturity, Pyrethrin I/Pyrethrin II ratio was lower in the irrigation treatment compared to rainfed treatment at physiological maturity (Figure 2b).

Rate of flower development and duration of flowering period

Irrigation had a significant influence on crop maturity and resulted in a larger spread of flower maturity stages at each sampling date, reflected by the lower value for flower maturity index in the irrigated treatment compared to the rainfed treatment (Figure 2e). As a result of higher rate of flower maturity in the rainfed treatment, flowers were dried rapidly and flower dry weights were markedly reduced due to loss of flower parts including ray florets and disc florets. Irrigation treatment applied throughout the flowering period significantly reduced the rate of flower development (p= 0.001) and increased the duration of flowering period (p<0.001), as a result of that, the harvesting date was delayed by eight days compared to the rainfed treatment (Figure 2f). According to the results of this experiment, 41-47 days after maturity stage 1 is a critical period. There is a sharp decrease in pyrethrin yield per flower in rainfed treatment, and a sharp increase under irrigation. Rate of pyrethrin accumulation is lower than for rainfed before day 41. Irrigation increases this rate quite late. Adequate water supply at the late flowering stage seems critical for flower growth (Fig. 1b) and pyrethrin accumulation per flower (Fig. 2d).

Conclusions

Based on the results of this experiment, we conclude that the application of irrigation throughout the -flowering period significantly increased flower yield as a result of enhancement in flower number and flower size. The increase in flower yield and pyrethrin concentration leads to greater increase in the pyrethrin yield under irrigation. Overall, adequate soil moisture for flower development in pyrethrum slows flower development and increases the duration of the flowering period compared to the 'rainfed' treatment. Overall irrigation has a major impact on the rate and duration of pyrethrin accumulation, resulting in higher pyrethrin yield per flower at physiological maturity. The findings of this study will be important to develop advanced agronomic strategies to maximise pyrethrin yield in pyrethrum.

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Evaporation and crop transpiration; behind the water use efficiency paradigm

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Abstract
We assembled published measurements of wheat water use which included both bare soil evaporation and crop transpiration in Australia in an effort to better define the critical parameters underpinning the "French and Schultz" water use efficiency schema. We found only 19 studies which measured the critical water balance parameters of bare soil evaporation and crop transpiration. Together these studies indicate that on average 38% of crop evapotranspiration is lost to direct soil evaporation under Australian rainfed wheat crops. We can find no data to support an increase in crop productivity due to increased crop transpiration at the expense of bare soil evaporation as a function of improvements in agronomic practices in recent decades.

Key words
Water balance, transpiration efficiency, wheat

Introduction

The strong correlation between rainfall and crop productivity has underpinned a useful conceptual framework (Figure 1A) that describes crop growth as a function of crop transpiration (T). While bare soil evaporation (Es) forms part of total crop water use (evapotranspiration, ET) it is unproductive. Diverting Es to T (Figure 1B) increases crop growth without increasing total water use. The slope of the line in Figure 1 is equivalent to transpiration efficiency (TE), the amount of dry matter produced per unit of water transpired. Where grain yield is plotted on the Y axis, the slope of the line would include effects flowering capacity and flowering success, grain development and effects of pests, diseases and frost on grain weight, and the effectiveness of grain harvest. In that case it does not represent TE.. Since Figure 1 defines the X axis as evapotranspiration, rather than rainfall + stored soil water as is often done, drainage and run off can be ignored. The greatest uncertainty in this framework is the X intercept, variation in Es relative to T, particularly in Australia where low rates of N fertiliser application might lead to slow leaf area development, leaving the soil surface exposed to direct radiation for longer. The application of this framework in Australia has been rather ad hoc, because the parameters have been poorly defined. In the seminal paper of French and Schultz (1984b), neither Es nor transpiration efficiency were actually measured. Here we examine the published measurements of the X axis intercept and the slope of the line of Figure 1 for wheat in Australia.

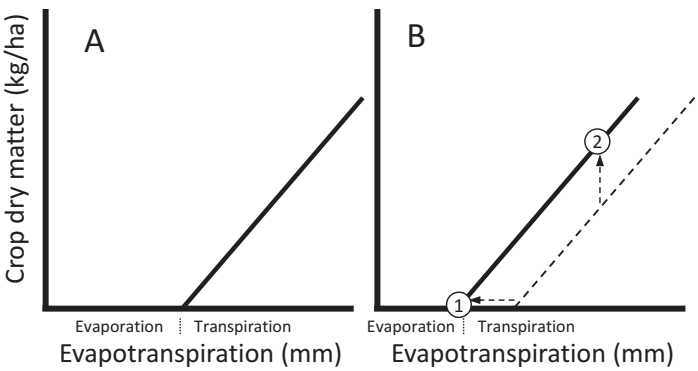

Figure 1(A) Relationship between crop water use (evapotranspiration) and crop dry matter production in a water limited environment. Water which is not transpired but is lost directly to the atmosphere via bare soil evaporation is not productive. (B) Diverting water to transpiration pushes the X intercept to the left (□), increasing dry matter production (□) without changing total evapotranspiration.

Review of available data

We compiled published estimates of the fractional contribution of Es to ET for wheat crops across the Australian cereal belt, each obtained by a combination of field measurement and modelling. We excluded

estimates derived wholly from modelling. From the available measurements, on average 40% of water use over the duration of a wheat crop is attributed to direct evaporation from soil, with values from 16 to 65%, or 36-171 mm evident. In comparison French and Schultz (1984a) concluded that only 33% (110 mm) of water use was lost as Es from soil under wheat crops across 24 sites in South Australia in the years they investigated (1964-1975).

Plotting seasonal evaporation from soil against seasonal evapotranspiration for the data we could find in the literature for 19 different sites across the cereal belt (data sources listed at end), it can be seen that seasonal ET accounted for 44% of the variance in seasonal evaporation from soil (Figure 2). As evaporation from soil must be 0 when ET is 0, we forced the regression through the origin. The slope of the regression in Figure 2 provides a convenient scaling for the X axis intercept of Figure 1A. The slope (0.38) is close to what has been considered typical (0.4) for well managed wheat crops in Australia (Richards 1991). There are insufficient data to examine possible regional differences.

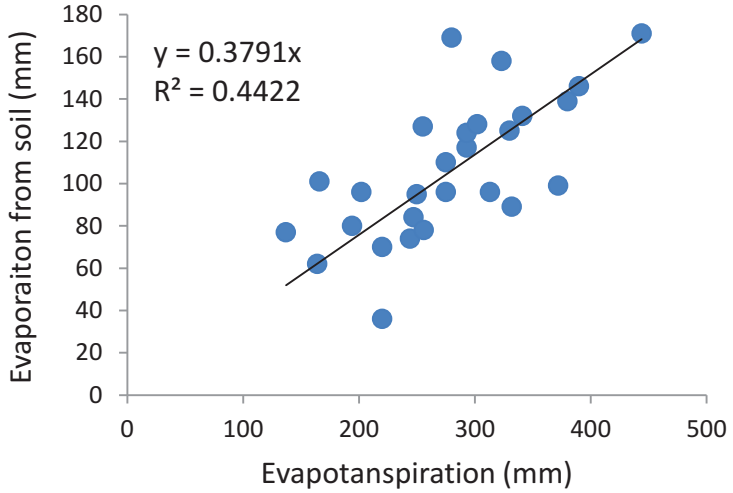

Figure 2Correlation between seasonal evaporation from soil and seasonal evapotranspiration for wheat crops in Australia. Data sources are given in Table 1. The regression is forced through the origin since by definition evaporation from soil must be nil when evapotranspiration is nil.

The studies illustrated in Figure 2 are primarily for crops grown before the widespread adoption of conservation tillage, earlier sowing, improved rotations with lower disease loads, and increased nitrogen application (Passioura 2002). These improvements may have increased the rate of leaf area development and thus crop transpiration relative to evaporation from soil. However we can find no water balance data to substantiate any such trend as there appear to be no published studies for crops grown after the year 2002.

The slope of the line in Figure 1 represents transpiration efficiency (TE), the relationship between net shoot dry matter gain and water transpired by the crop. Estimates of TE for wheat in Australia range from 33 (Doyle and Fischer 1979) to 73.4 kg/ha/mm (Sadras *et al*. 2005), averaging 49 across 13 published studies. In a general sense TE is thought to be a conservative parameter, with the largest external influence being the leaf to atmosphere vapour pressure deficit (VPD) (Morison and Gifford 1984). Decreasing VPD, as one moves from the northern to the southern Australian cereal belt, might increase TE by about 2.6% per degree of latitude, or from ca 40 to 55 kg/ha/mm (Rodriguez and Sadras 2007). Such effects of VPD on TE are often accounted for using a crop specific constant (see e.g. Hammer and Muchow 1994,Tanner and Sinclair 1983). Constants scaling TE for wheat to account for VPD of 4.7 (Meinke *et al*. 1997) and 5.2 (Young *et al*. 2008) have been reported. There is large variation in TE apparent in the literature for a given crop, regardless of VPD scaling. Some of this may be due to differences between cultivars (e.g. Condon *et al*. 1990; Hammer *et al*. 1997; Hubick 1990; López-Castañeda and Richards 1994; Sadras *et al*. 1991). Furthermore, inherent in the transpiration efficiency term is an assumption (typically unstated) about allocation of photosynthate to roots which might account for some of the difference in apparent TE. Differences in soil water and nutrient availability, and pests and diseases, may alter the relative allocation of fixed C to roots such that apparent shoot TE may be quite different to actual TE.

Conclusion

The slope of the line in Figure 2 provides a convenient starting point for defining the fraction of seasonal evapotranspiration lost as bare soil evaporation for field application of the water use efficiency schema of Figure 1. However it is based on relatively few measurements and none from the last 13 years. If we were to assume that improved agronomy results in greater crop transpiration at the expense of direct soil evaporation, more contemporary measurements need to be made. Similarly the transpiration efficiency for wheat needs to be better defined as a function of cultivar and VPD environment. Values for transpiration efficiency used in current models are based on very few measurements.

NOTE: data from Figure 2 are sourced from Adcock (2006), Angus and van Herwaarden (2001), Condon *et al*. (2002), Doyle and Fischer (1979), Gregory *et al*. (1992), Hamblin *et al*. (1987), Leuning *et al*. (1994), López-Castañeda and Richards (1994), Condon *et al*. (1993), Perry (1987), Siddique *et al*. (1990), Simpson and Siddique (1994), Young *et al*. (2008), Yunusa *et al*. (1993).

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Yield advantage and water productivity of maize-mungbean inter-cropping systems in the Dry Zone of Sri Lanka; a modelling approach

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Abstract
Water is not efficiently used in most of the cropping systems in South Asia. Therefore, water-efficient agricultural practices are of immense importance when increasing the area to be cultivated, and/or conserving rain water to be used in drier regions through irrigation. Inter-cropping of maize (*Zea maize* L.) with mungbean (*Vigna radiate* L.) R. Wilczek may offer benefits in utilising water efficiently and maintaining or improving land productivity. Simulation models are useful tools to assess the performance of agricultural systems. The present study was conducted to evaluate the irrigation water requirement and yield of the maize-mungbean inter-cropping system in comparison with mono-cropping, using APSIM. Simulation results revealed that the maize-mungbean intercrop required only 4 % more water than the maize mono-crop ($P>0.05$). Moreover, intercrop maize yield was only 3 % less than that of the maize mono-crop ($P>0.05$) However, yield of mungbean was 21 % less in the inter-cropping system than the mono-crop system ($P<0.05$). The land-equivalent ratio of the maize-mungbean inter-cropping system was 1.8. Efficient use of water under the inter-cropping system, with a similar yield of maize to that obtained under mono-crop of maize, combined with an additional mungbean harvest highlights the greater efficiency of the maize-mungbean inter-cropping system in the Dry Zone of Sri Lanka.

Key words
APSIM, Evaluation, Inter-cropping, Maize, Mungbean, Sri Lanka,

Introduction
Water scarcity for crop production occurs in many parts of the world, mainly due to inefficient water management practices, resulting in very low water productivity, i.e. the amount of biomass or yield produced per unit water input (Thiyagarajan and Selvaraju, 2001; UNESCO-WWAP, 2009). Therefore, water efficient agricultural practices are of immense importance when increasing the area to be cultivated, and/or conserving water from rain to be used in drier regions or seasons through irrigation.

Inter-cropping is the simultaneous growing of more than one crop species in proximity, with the aim of increasing productivity per unit land area and time. Cereal-legume inter-cropping is practiced mainly in tropical regions of the globe (Hauggaard-Nielsen et al., 2001; Agegnehu et al., 2006; Dhima et al., 2007). Maize (*Zea mays* L.) is a major cereal crop grown in Sri Lanka, with an annual cultivation area of 30,000 ha. Mungbean (*Vigna radiate* (L.) R. Wilczek) is a major legume in the rain-fed farming systems in the Dry and Intermediate Zones of Sri Lanka. Inter-cropping of maize and mungbean may utilise water efficiently and improve land productivity.

Simulation models are useful tools to assess the performance of agricultural systems under different scenarios. The Agricultural Production Systems Simulator (APSIM) is a farming systems model that simulates the effects of environmental variables and diverse management decisions on production (crops, pasture, trees, and livestock), profits, and soil conditions (Keating et al., 2003). The model can be used to analyse risks and explore alternative management options such as irrigation management, crop choice, planting date, and fertiliser rate using local climate and farm specific soil data. The present study was conducted to evaluate the irrigation water requirement and yield of the maize-mungbean inter-cropping system in comparison with mono-crops using APSIM in the Dry and Intermediate Zones of Sri Lanka.

Materials and Methods

Parameterization of the APSIM Model

The maize and mungbean modules in APSIM 7.5 were parameterised for Sri Lankan cultivars. Phenological parameters for cultivars *Ruwan* (maize) and *MI6* (mungbean) were based on literature values (Amarasingha et al., 2014). The *maize.ini* and *mungbean.ini* files in APSIM were modified accordingly to simulate the crop productivity at Maha-Illuppallama (MI) area in the Dry Zone low country (DL) of Sri Lanka. The dominant soil in the study area was a Reddish Brown Earth (Mapa *et al.*, 2010). Daily weather data (maximum and minimum temperatures, rainfall, and solar radiation) from January 1976 to December 2014 for MI were sourced from the Natural Resource Management Centre of the Department of Agriculture, Sri Lanka.

Model evaluation

Secondary data on yield were sourced from the Field Crops Research and Development Institute (FCRDI) at MI. Fertilizer and management practices were adjusted according to the recommendations of the Government Department of Agriculture of Sri Lanka. Planting dates, planting method (direct seeding), and management strategies were adjusted in the model simulations as recorded at FCRDI. The simulated yield and phenology were compared with the observed values collected from the literature. Simulated and observed data were plotted on a 1:1 graph of predicted and observed values for cultivars *Ruwan* (maize) and *MI6* (mungbean). The statistical measures used for comparing simulated and observed data were: coefficient of variance (CV), root mean squared error (RMSE), coefficient of determination (R^2), and Student's t-test.

Definition of Scenarios Modelled

In order to test the changes in water and land productivities of the maize-mungbean inter-cropping system in comparison with corresponding mono-crops, simulations were run in *Yala* (minor rainy season from March to September) and *Maha* (major rainy season from October to February) seasons at MI with 37 years of historical climate data. The maize mono-crop had a row spacing of 60 cm with a sowing density of 5.5 plants m^{-2}. The row spacing of mono-crop mungbean was 30 cm, with a sowing density of 33 plants m^{-2}. In the inter-cropping system maize plant density was unchanged (*i.e.* 5.5 plants m^{-2}) and the mungbean plant density was reduced by 50 % (*i.e.* 16.5 plants m^{-2}). These inter-crop densities were based on farmer practice. Both crops in the inter-crop were sown on the same day. Irrigation was supplied in 7-day intervals until the soil reached field capacity, consistent with farmer practice. The grain yields of maize and mungbean under both mono-cropping systems and the inter-cropping system were simulated. Land Equivalent Ratio (LER-sum of the ratio of inter-crop productivity in comparison with mono-crop productivity) was calculated to determine the land productivity.

Results and Discussion

The relationship between observed and simulated maize grain yield during the model evaluation stage was strong (R^2 value of 0.98 for *Ruwan*) (Fig. 1) indicating that the parameterised model could explain a high level of the total observed variability in grain yield. Student's t-test found no significant difference between the observed and simulated grain yield values (P=0.7). The RMSE for *Ruwan* was 190 kg ha^{-1}.

The parameterised APSIM-mungbean module simulated the grain yield of mungbean variety *MI6* with R^2 of 0.97, indicating that the parameterised model could explain a high level of total observed variability in grain yield (Fig. 1). The RMSE for *MI6* was 75 kg ha^{-1}. This compares favourably with the observed experimental variability (standard deviation of 598 kg ha^{-1}), and hence the model predictions were within the bounds of experimental uncertainty. Student's t-test found no significant difference between the observed and simulated grain yield values (P=0.8). Therefore, the parameterised APSIM-maize and APSIM-mungbean models can acceptably simulate the yield of *Ruwan* and *MI6* at MI region in the DZ under optimal crop management.

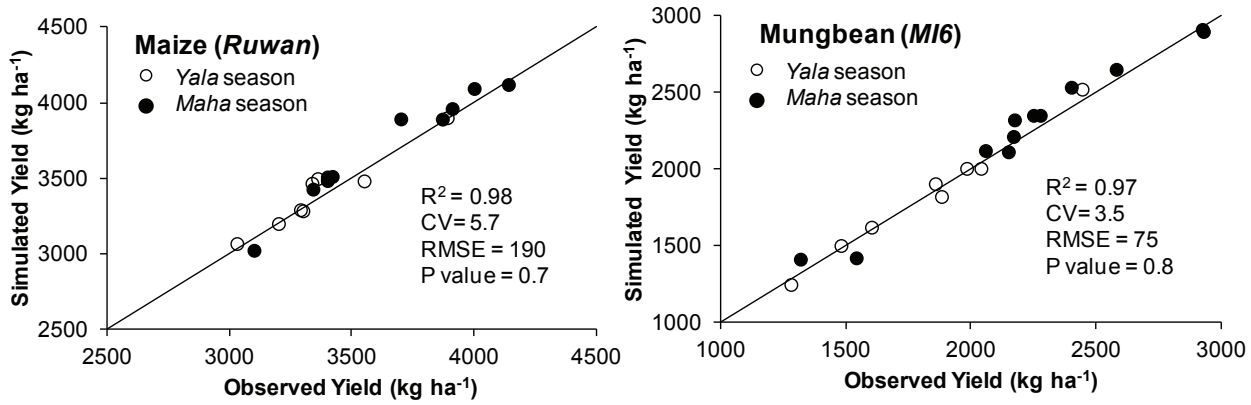

Fig. 1. Observed and simulated yield of maize (*Ruwan*) and mungbean (*MI6*) varieties in *Yala* and *Maha* seasons at Maha-Illuppallama under standard management practices at the model testing stage. The line indicates the 1:1 relationship.

Simulations of mono-crop mungbean required 50 % less water than the mono-crop of maize ($P<0.05$, Fig. 2), and the maize-mungbean intercrop required only 4 % more water than the mono-crop of maize ($P>0.05$, Fig. 2). Simulated maize yield was only 3 % higher in the inter-cropping system than in the mono-crop ($P>0.05$) whereas mungbean in the intercrop was 21% less than that in the mono-crop ($P<0.05$). The LER value of maize-mungbean inter-cropping system was 1.8. Therefore, inter-cropping of maize and mungbean has advantages over the mono-cropping of maize or mungbean at MI in the DZ of Sri Lanka.

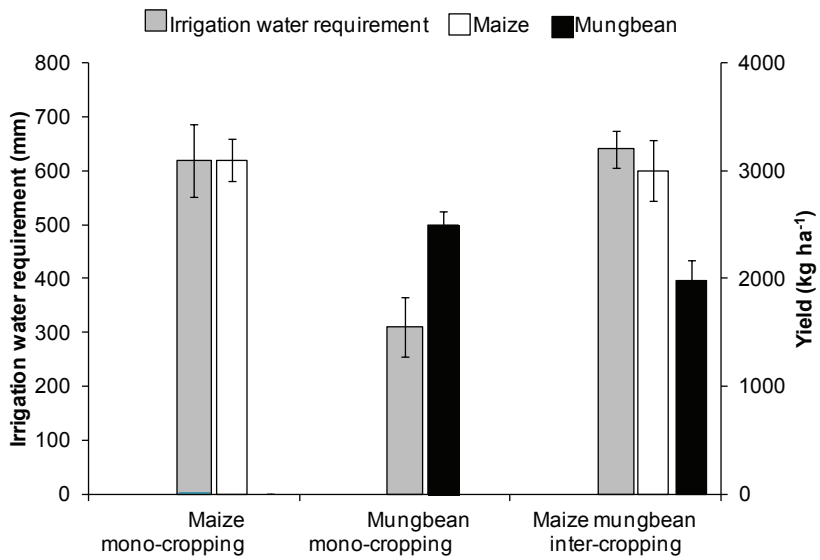

Fig. 2. The irrigation water requirement and yield of maize and mungbean in mono-cropping and inter-cropping systems during *Yala* season at Maha-Illuppallama.

Conclusion

The maize-mungbean intercrop utilises water efficiently, without significantly reducing the maize yield compared with the mono-crop of maize, and producing an additional mungbean yield, thus improving the land productivity.

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Data requirements for automated model-based control of irrigation and fertiliser application

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Abstract
Model-based adaptive control strategies can be used to determine site-specific irrigation and fertiliser volumes with the aim of maximising crop water use efficiencies and/or yield. These strategies use a crop model to predict the crop's response to climate and management throughout the crop season, and identify which irrigation and fertiliser application volume and timing produces the desired crop response or condition (e.g. maximum yield). The model can be calibrated with infield weather, soil and crop measurements to ensure the model predictions accurately reflect infield measurements. However, data collection of soil and plant parameters spatially over a field and throughout the crop season will potentially lead to a large sensed data requirement which may be impractical in a field implementation. In addition, not all the data may be required to calibrate the crop model with sufficient accuracy. A smaller dataset consisting of only the most influential sensor variables may be sufficient for adaptive control purposes.

This paper reports on a simulation study which evaluated the relative significance of weather, soil and plant variables (either individually or in combination) for calibration of the APSIM french bean crop production model. This involved comparing the outputs of a crop with variations in evaporative demand, soil moisture, leaf area, canopy size and/or thermal time for growth stages. The most significant parameters for the simulated pod size, height, soil moisture and total nitrogen were the thermal times for each growth stage.

Key Words
APSIM simulation, beans, adaptive control, optimisation

Introduction
Crop production models can be used to simulate the soil and plant response to irrigation and fertiliser inputs for manual what-if scenario analysis, and, potentially, automated irrigation and fertiliser control systems. The automated control system would iteratively execute the model with different irrigation and fertiliser treatments and select the treatment that maximised water use efficiency or yield (McCarthy et al. 2011).

An automated model-based control system will be evaluated for a french bean crop in Kalbar, QLD in 2016. However, the crop model must accurately reflect the infield conditions to be used for on-farm management. The crop models can be calibrated by adjusting input parameters that define how the plant produces vegetation and fruit and consumes nutrients and water in response to the weather and soil properties. To automate the calibration procedure of crop models (e.g. in APSIM), all possible combinations of soil and crop parameter values may be evaluated. However, simulating all of the possible combinations of parameters to calibrate crop models would be time-consuming and computationally intensive. For example, there are 21 crop growth-related parameters in the french bean crop properties file and there would be $3^{21} = 10.5 \times 10^9$ possible combinations of parameters to evaluate for three possible states of each parameter. Hence, only the parameters with the greatest effect on the crop model outputs are adjusted in the calibration procedure.

Materials and method
A sensitivity analysis was conducted to identify the most influential input parameters in the french bean crop model. The sensitivity analysis involved the following procedure:
1. Identifying the model input parameters and output variables
2. Executing the model with a range of input parameter values that define how the plant grows and recording the output variables
3. Calculating a sensitivity index to quantify the difference in each output with the adjustment of each input parameter
4. Ranking the influence of each parameter on the model output

Identification of model input and output parameters
For the sensitivity analysis, the simulated response was analysed after each input parameter was adjusted between an appropriate minimum and maximum value. The lower and upper ranges of the input parameters utilised in the sensitivity analysis 50% of the value and the upper range utilised was 150% of the default value of the corresponding parameter in the input files. The parameter input values that were evaluated were equally distributed at sampling points between the lower and upper limits of input parameter (Table 1).

Table 1. Crop parameters in french bean APSIM input variety file

Parameter	Original value	Range of values	Interval
thermal time for emergent	100	50-150	10
thermal time for vegetation	529	264-794	53
thermal time for flowering	185	90-280	19
thermal time for pod filling	265	130-400	27
main stem final node number	40	20-60	4
height during cooler temperatures	50	25-75	5
height during higher temperatures	750	375-1125	75
branching rate at each growth stage	0	0-1	0.1
maximum size of pod	0.68	0.34-1.02	0.068
mortality of each growth stage	0	0-1	0.1
filling rate of early growth stage	0.002	0.001-0.003	0.0002
filling rate late pod growth	7E-.05	3.5E-.05-10.5E-.05	0.7E-.05
water content at each growth stage (start pod growth, end grain fill, maturity, harvest)	0.93	0.465-1.395	0.093
proportion of leaf area killed by frost	0	0-1	0.1

The output variables considered in this sensitivity analysis were soil moisture content, total nitrogen, pod size and plant height. These were selected because they are the most likely to be measured in a field experiment and used to calibrate the growth model.

Model execution
A one at-a-time analysis was conducted which involved repeatedly varying one parameter at a time while fixing the other parameters (Hamby 1994) and evaluating the effect of changing each input parameter on the modelled outputs. The one-at-a-time analysis was conducted for a range of field conditions. This is because if the analysis was only conducted for one particular combination of weather, plant and soil properties and irrigation treatment, the variation in the output may be dependent on the set of field conditions used. A total of 54 possible sets of field conditions were evaluated as follows:

- Two soil types: grey sandy loam and brown clay loam with starting soil moisture content of 100%
- Three irrigation treatments: 10, 20 and 30 mm applied at 20, 30 mm and 40 mm soil moisture deficit, respectively
- Three fertiliser treatments: 15, 25 and 35 kg N/ha applied at 40, 50 and 60 kg N/ha deficit, respectively
- Three weather profiles: Kalbar, QLD for GPS location -27.898960°N and 152.631759°E for three seasons over 2012-2014 obtained from Australian Bureau of Meteorology SILO data set.

A total of 12474 simulations were conducted for the sensitivity analysis (with the 10 adjustments made to each of the 21 input parameters with 54 sets of field conditions). Daily simulated output was recorded for soil moisture content, total nitrogen, pod size and plant height for each simulation.

Calculating the sensitivity indices
Separate sensitivity indices were calculated for each set of field conditions and day of the crop season. This ensured that any variation in the simulated response was caused by the adjustment of an input parameter rather than the temporal variation of the crop response and/or a change in the weather, soil or plant properties. The sensitivity index ($Si_{p,r,i(t)}$) was calculated (Hamby 1994) as follows:

$$SI_{p,r,i}(t) = \frac{D_{p.r.i.max}(t) - D_{p.r.i.min}(t)}{D_{p.r.i.max}(t)}$$

where $D_{p,r,i,max(t)}$ and $D_{p,r,i,min(t)}$ are the respective maximum and minimum simulated values of output r (i.e. soil moisture content, plant height, pod size) when the pth parameter is adjusted over its range and for the ith combination of field conditions and day t.

The sensitivity indices were combined to quantify the overall sensitivity of each simulated output to each input parameter. The first-order indices are commonly averaged to measure the overall sensitivity of the output to each input parameter (Braddock & Schreider 2006). Hence, the sensitivity indices for each field condition and day were averaged as follows:

$$\mu_{p,r} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{d}\sum_{t=1}^{d} SI_{p,r,i}(t)\right)$$

where $\mu_{p,r}$ is the mean sensitivity index, N is the total number of field conditions (81 in this case) and d is the number of days in the simulated crop season. Averaging the daily sensitivity indices throughout the crop season masks the temporal changes in the most significant parameters; however, it also identifies the most significant parameters over the entire crop season.

Discussion

The averaged sensitivity indices for each parameter in the french bean model are shown in Figure 1 for the simulated soil moisture, total nitrogen, plant height and pod size. These indices were assigned ranks from one (highest) to 21 (lowest) where the lowest summed rank was the most significant parameter (Table 2). For each simulated output the sensitivity indices were summed to determine the overall ranking of each parameter (last column of Table 2). From these rankings the following observations were made:

- The thermal time and branching rates for the vegetation, flowering and pod filling stages were the highest overall rank for the pod size, height, soil moisture and total nitrogen. This suggests that the day degrees for growth stages and, hence, weather station data, are required for crop model calibration.
- The most influential parameters for the simulated pod size were thermal time for pod flowering and vegetation, branching rate during vegetation and late pod filling rate. It was expected that pod filling rate would be the most influential parameter for simulating pod size, however the filling rate of late pod growth was only the fourth most influential parameter. This is likely because the sensitivity index was averaged over the season with each day weighted equally although the pod filling occurs over a short period of time (i.e. days). This suggests that the influence of each parameter differs depending on the time the season. Another sensitivity analysis is required that calculates a sensitivity index for each crop growth stage.
- For the simulated bean plant height, the highest ranking crop parameters were height growth after flowering, thermal time for vegetation, and branching rate during vegetation. These parameters are all related to vegetation.
- For the simulated soil moisture content, the thermal time for vegetation and flowering, and branching rate during vegetation were the most influential parameters. This is consistent with the properties of crop water use and soil moisture content which are affected by both vegetative growth and fruit production.
- For the nitrogen simulations, the thermal time for the vegetation, flowering and pod filling stages had the highest ranking.
- The plant water content and proportion of leaf area killed by frost had the smallest influence on the simulated outputs. This is because there was no frost during the simulated bean season.

Conclusions

A sensitivity analysis has been conducted to identify the most significant parameters in the calibration of the french bean module in APSIM. In this analysis, the most significant parameters for the simulated pod size, height, soil moisture and total nitrogen were the thermal times and branching rates for each growth stage and filling rate of pods. These parameters influence both the vegetative and fruiting growth throughout the crop season. This suggests that calibrations of the french bean module for model-based control systems should focus on measurement of weather, plant height and pod size to ensure accurate calibration of the french bean model. Further simulations and analysis will be conducted for different growth stages of the bean crop.

Acknowledgements

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Figure 1. Sensitivity analysis results

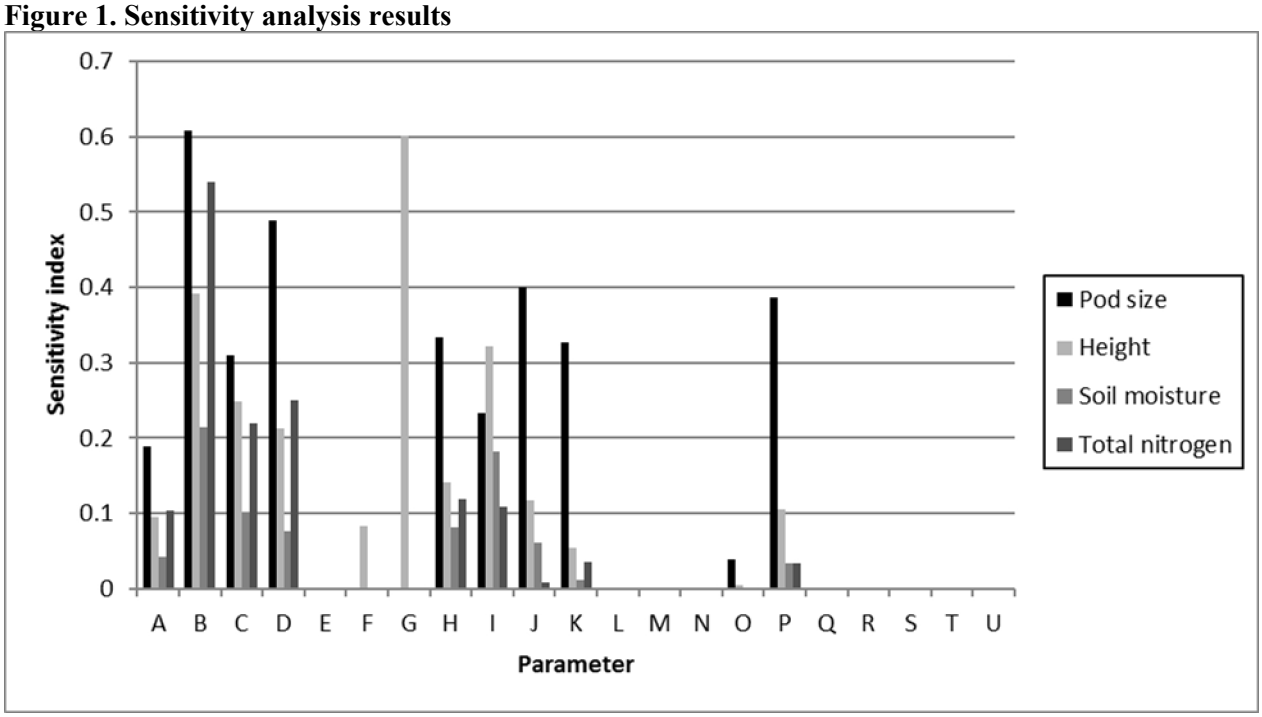

Table 2. Ranks of the first-order sensitivity indices for each parameter

ID	Parameter	Pod size	Height	Soil moisture	Total nitrogen	Overall rank
A	thermal time for emergent	9	9	7	6	8
B	thermal time for vegetation	1	2	1	1	1
C	thermal time for flowering	7	4	3	3	3
D	thermal time for pod filling	2	5	5	2	2
E	main stem final node number	11	13	11	11	12
F	height growth before flowering	12	10	12	12	13
G	height growth after flowering	13	1	13	13	10
H	branching rate during emergence	5	6	4	4	5
I	branching rate during vegetation	8	3	2	5	4
J	branching rate during flowering	3	7	6	9	6
K	maximum size of pod	6	11	9	7	9
L	mortality of early pod growth	14	14	14	14	14
M	mortality of mid pod growth	15	15	15	15	15
N	mortality of late pod growth	16	16	16	16	16
O	filling rate of early pod growth	10	12	10	10	11
P	filling rate of late pod growth	4	8	8	8	7
Q	water content at start pod growth	17	17	17	17	17
R	water content at end grain fill	18	18	18	18	18
S	water content at maturity	19	19	19	19	19
T	water content at harvest	20	20	20	20	20
U	proportion of leaf area killed by frost	21	21	21	21	21

Plant growth regulator use in broad acre crops

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Abstract
There is little reliable information on how, why and on which crops plant growth regulators (PGRs) are currently used in Australia. Such information is needed to better link research and development with extension. Currently the four main classes of PGRs used in Australia include Ethephon (ETH), onium-types (chlormequat, CCC), and second and third generation PGRs; the triazoles (e.g. tebuconazole, TEB) and trinexapac-ethyl (TE), respectively. Of these, only CCC, TEB, TE are registered for use in cereals and none for canola. To better understand current usage of PGRs in grain crops, a telephone survey of 142 agronomists working across Australian grain growing regions was conducted. Participants provided information relating to PGR usage on the range of crops grown in their area, including, rates of application, reasons for use, response of crops/effectiveness, and a variety of other variables. The potential economic contribution of PGR to the grains industry was estimated from analysis of reported yield gains from application of PGR to wheat in the high rainfall zone (HRZ). Application of PGR with no change in yield from, for example, a 2.38 Mha area (representing 70% of the HRZ) would lead to a cost of around $70M. In contrast, there was an estimated net benefit of $35M and $138M for a 5 and 10% increase in grain yield in the HRZ. This research highlights the need to better understand use of and yield responses to PGRs under a range of climatic, regional and cultivation situations, through co-ordinated research and extension.

Introduction
Plant growth regulators (PGRs) were developed as a tool for growers to manage lodging risk in a range of grain crops. The most widely evidenced effect in the scientific literature for PGRs is the reduction of plant height when PGRs are applied at early stem elongation in cereals (Berry *et al*. 2004) or rosette formation in canola. Shorter plant height improves crop resistance to lodging and can improve harvestability and possibly grain quality where lodging is associated with increased sprouting. In some instances PGRs have been linked to an increase in stem strength (Tripathi *et al*. 2004) and number of roots (Emam and Shekoofa 2009). Research into the effect of PGRs on grain yield has generated inconsistent conclusions, which may reflect the complex interaction between crop species and variety, the type, rate and timing of PGR application with respect to plant phenology, and environmental conditions. Some improvement in yield has been reported in response to PGRs used on wheat but generally not for either barley or canola, although there are some exceptions (Berry and Spink 2009). Three PGRs are now registered for use in cereals in Australia, chlormequat (CCC), trinexapac-ethyl (TE) and ethephon (ETH) but the current use of PGRs remains unknown. To better understand current usage and perceptions of PGRs in grain crops, a broad ranging telephone survey of agronomists from across Australian grain growing regions was conducted. Potential economic contribution of PGRs to the grains industry was also investigated through economic analysis.

Methods
The survey instrument used in this study was designed to generate understanding of PGR usage across Australian grain growing regions, and reasons agronomists recommended use in their region. Both quantitative (scale and ordinal) variables were included, as well as open-ended qualitative questions to provide insight into perspectives and concerns of agronomists across the grain growing areas. A broad and inclusive sampling frame was employed to cover the growing areas and capture the diversity of perspectives on, and applications of, PGRs. Participants were recruited via internet searching and direct contact with agricultural stores in each Australian agro-ecological zone. The resulting list of 218 potential participants developed within the Tasmanian Institute of Agriculture (TIA) was provided to third-party Computer Assisted Telephone Interviewers (CATI) from the Central Queensland University Population Research Laboratory (PRL). PRL were also provided with the survey instrument and instructions on its application by the TIA research team. Of the 218 potential participants, 71 either declined to be involved, were ineligible or not contactable. In total, 142 agronomists were interviewed by telephone. Final survey data were analysed within TIA using descriptive and analytical

statistical methods. Common rationales for specific actions or decisions in PGR use and perceived effectiveness were identified to the open-ended survey questions. Most of the open-ended questions elicited consistent responses across grain growing areas and were thus reclassified into nominal categories to assist with communication of results. Each participant was invited to discuss the four main crops that they managed, and data was collated by crop, resulting in data for 474 crop areas managed. This paper will report results from the PGR survey related to wheat, which was the main crop managed by participating agronomists. The study was approved by the UTAS Human Research Ethics Committee (reference number: H0013500).

Results

Why do agronomists recommend PGR use?

Of the 142 agronomists who participated in the survey, 29 (20%) reported recommending PGRs for application in wheat. The extent of use was low for these participants; 66% of respondents recommended PGR use on wheat for less than 5% of the hectares they managed, and only 10% of respondents recommended PGRs for greater than 40% of hectares under their management. The agronomists who recommended PGRs generally reported higher yields for wheat (4.0 t/ha) than those who did not recommend PGRs (3.1 t/ha), however, this appeared to be related to the region or rainfall zone the agronomists were working in. The larger biomass production associated with increased yield requires greater crop inputs and PGRs are well-recognised as one management strategy to manipulate canopy size to reduce lodging (Pinthus 1973; Berry et al. 2000; Berry and Spink 2009). The majority of respondents (69%) who recommend PGRs, recommended that growers apply a combination of two PGR products.

Only 10% of respondents reported two applications per season while the majority of respondents (86%) reported only one application of PGRs per season. There was some variation in the timing of PGR application (Table 1), however most agronomists (76%) applied PGR at the early stem elongation stage.

Table 1. Growth stages at which PGRs are generally recommended for wheat

Growth Stage	Number of respondents (%)
Booting	1 (3%)
Early stem elongation	22 (76%)
Late stem elongation	2 (7%)
Late tillering	3 (10%)
TOTAL	**29 (100%)**

Benefits of PGR use

When asked to explain the benefits from using PGRs in wheat, participating agronomists most frequently reported reduction in lodging risk and, related height reduction (Figure 1). Yield was also reported as an important benefit. Harvestability and straw strength/thickness may also relate to the observed benefit of height reduction, with those three rationales all indicating a more compact growth habit and improved harvestability.

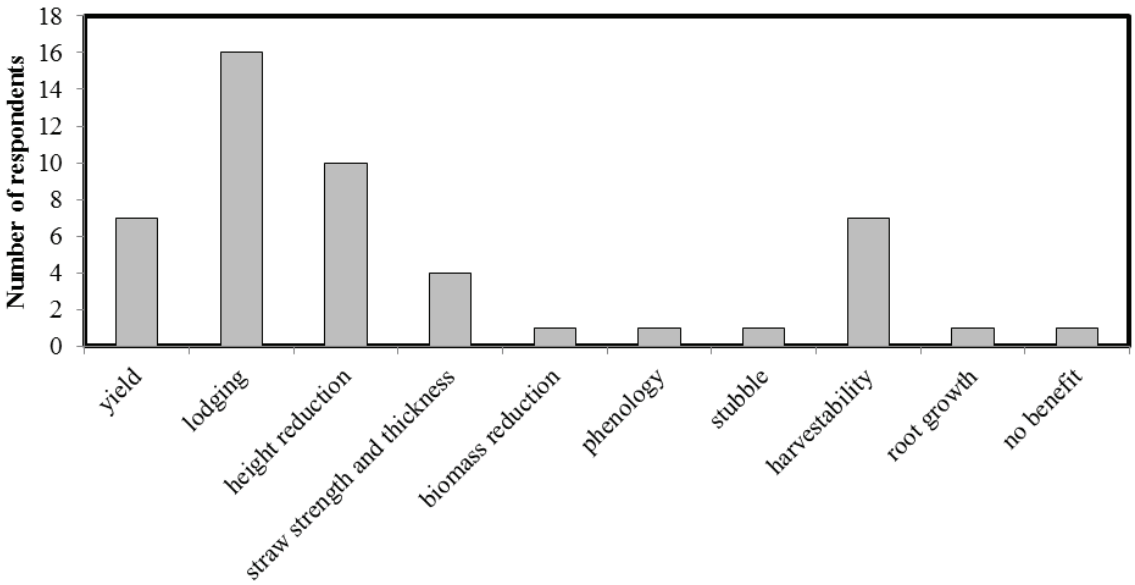

Figure 1. Benefits described by agronomists from the use of PGRs in wheat.

Why do agronomists not recommend PGR use in wheat?
Agronomists who did not recommend PGRs for application to wheat provided insights into the perception and experience of agronomists who had either tried these products previously, or were unconvinced by the evidence of their efficacy (Figure 2). The most frequent rationale was that PGRs were not needed in the area the agronomist managed. This was usually related to typical yields for the region or rainfall zone that the agronomist worked in, with agronomists in low yield areas most often mentioning the theme 'not needed'. The related theme of 'not suitable in the environment or area' was also mentioned by many of the participants. An important theme to emerge from this question was an economic one where agronomists said that the application of PGRs to the crops they managed did not provide a justifiable return on the cost of application, and related to this was the theme that the science or evidence of the effectiveness of PGRs was perceived to be weak or lacking.

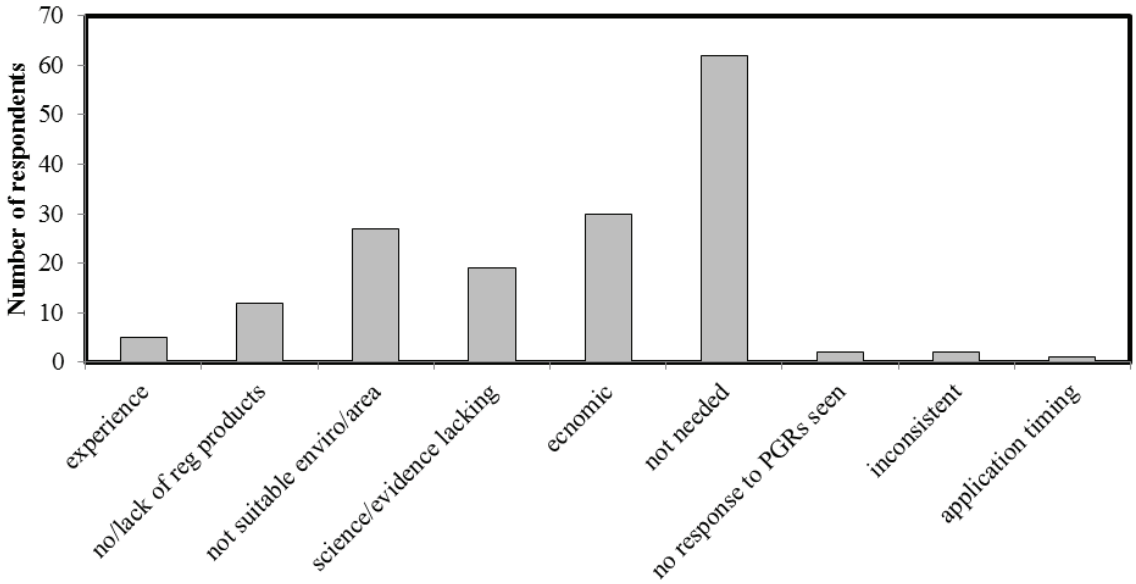

Figure 2. Agronomists' reasons for not recommending PGR use in wheat.

Economic analysis
The most certain economic benefit that was associated with PGR use was a reduction in plant height and an associated improvement in lodging resistance, leading to improved harvestability. This was perceived to reduce the loss of grain through shattering or poor quality. Indirect benefits included potentially reduced cost of harvesting, through reduced effort to harvest of crops with a high incidence of lodging, and through less expenditure on harvesting technologies to reduce grain losses. PGRs were also likely to improve dry-matter partitioning in grain, particularly in the high rainfall zone (HRZ). In the HRZ, a combination of higher rainfall and higher input can lead to greater relative production of vegetative matter.

As an example, the area planted to wheat in HRZ is ~2.38 Mha estimated as 70% of the total area of the high rainfall zone (3.4 Million ha) (ABS 2011). Average yields are around 4 t/ha (Sylvester-Bradley et al. 2012), which puts total annual wheat production from the high rainfall zone at around 9.52 Mt.

Table 2. Economic analysis for return on investment from use of the PGR Moddus® for a nil, 5 or 10% increase in grain yield in the HRZ. Assumptions are described in the text.

Item	Base line	Change in grain yield		
		0%	+5%	+10%
Area (Mha)	2.4	2.4	2.4	2.4
Yield (t/ha)	4.0	4.0	4.2	4.4
Total yield (Mt)	9.5	9.5	10.0	10.5
Return at $220/t ($M)	2094.4	2094.4	2200.0	2303.4
Cost at $30/ha ($M)	0	71.4	71.4	71.4
Net Return ($M)	2094.4	2023.0	2128.6	2232.0
Net Benefit ($M)	0	-71.4	34.2	137.6

The analysis in Table 2 shows the potential economic returns to the grains industry if PGRs return 0%, 5% and 10% increases in grain yields. A long term average wheat price of $220/t is assumed, along with the current price of the most expensive PGR (Moddus, $770 for 5L), which equates to $30/ha when applied at the recommended rate of 1.2 L/ha. As could be expected, application of PGR with no change in yield from a 2.38 Mha area would lead to a cost of around $70M. In contrast, there was a net benefit of around $35M and $138M for a 5 and 10% change in grain yield in the HRZ.

Conclusion

PGRs are generally reported and perceived to reduce plant height in grain cereals when applied at the appropriate stage of development; improvement in grain yield, however, tends to be inconsistent. A survey of 142 Australian agronomists found that only 20% recommend the use of PGRs in crop management of wheat, and their main rationale for recommending PGR use was improved lodging resistance, followed by height reduction and improved yield. Reasons why agronomists did not recommend PGR use in the crops they managed were because they were 'not needed' or unsuited to their region. Economic analysis showed that application of PGR to 70% of the HRZ with no change in yield would cost around $70M. In contrast, there would be a net benefit of ~ $35M and ~$138M if application of PGRs to wheat in the HRZ generated a 5 and 10% change in yield, respectively.

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Re-evaluating mepiquat chloride use in Bollgard II® Cotton

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Abstract
During the reproductive growth phase, there is competition for water, nutrients and carbohydrates between vegetative and reproductive growth in cotton plants. Plant growth regulators (PGR) such as mepiquat chloride (anti-gibberellin, MC) may be useful to slow new vegetative growth and instead promote reproductive growth. Previous PGR recommendations were based on conventional cotton cultivars rather than high lint-retention Bollgard II® cultivars. This paper describes field experiments over two growing seasons (2012/13 and 2013/14) with the main objective being to re-evaluate the use of Vegetative Growth Rate (VGR) for early season MC decisions in Bollgard II. Experiments also evaluated a multiple rate approach versus a single application of MC. Results showed that that relative yield responses to VGR differed compared with past experiments. At high VGRs yield was improved with the application of MC, however at low VGR yield reductions were substantially greater than previously reported. Yield reduction was associated with the higher fruit load in Bollgard II crops. Use of MC on Bollgard II crops require caution especially if crops have low VGRs, and this information will be used to revise industry recommendations.

Key words
Squaring, *Gossypium hirsutum*, Vegetative Growth Rate (VGR), mepiquat chloride

Introduction

After flowering, there is competition for water, nutrients and carbohydrates between vegetative and reproductive parts of the cotton plant (Gossypium hirsutum L.). This is normally regulated by the plant as described by Williams et al. (2012), but in some situations can become unbalanced where vegetative growth dominates, potentially reducing yield. In this situation, use of growth regulators such as mepiquat chloride (MC) could be considered by industry to modify the pattern of growth and development of cotton plants.

In making the decision to apply MC, it is important to consider why excessive vegetative growth occurs in cotton. One method used by industry to assist in making these decisions is by measuring Vegetative Growth Rate (VGR) at the early flowering growth stage to identify excessive growth. To date VGR however has only been validated in conventional cotton and not higher yielding Bollgard II® cotton crops; hence there is a need to re-evaluate the effectiveness of this method for the newer varieties.

Methods

The experiments were based at the Australian Cotton Research Institute, Narrabri, NSW, Australia. Experiments were conducted over two growing seasons 2012/2013 (Exp. 1) and 2013/2014 (Exp. 2). In Exp. 1 two different crop types with low and high vigour (VGR) were established using Bollgard II® cultivar Sicot 74BRF according to current production methods. The low VGR crop was planted mid October (normal planting time) and the high VGR crop was planted late (early December). The high VGR crop received an additional 200kg/ha of urea in late December. In Exp. 2, only the high VGR crop was grown. Both experiments had in excess of 300 kg/ha of available soil N at planting.

Three MC treatments (nil, single application of 900 ml/ha, and three applications of 300 ml/ha) were applied in the low vigour treatments in experiments 1 and 2. The timing of the single application was at first flower (where 50% of plants have a white flower), while the multiple application treatment had MC applied at squaring (i.e. budding), first flower and 2 weeks after first flower application (Table 1).

All experiments used a randomised complete block design with four replications. Plots were 12m long by 4 m (4 rows) wide. There was also a 22 m buffer located at both the head ditch and tail drain. MC was applied using a calibrated hand held spray boom (width 4m).

Table 1. Date (including days after planting) of Mepiquat Chloride applications

	Single Treatment (First flower)	Squaring	Multiple Treatments First flower	2 wks> First flower
Exp. 1 Low VGR	27/12/2012 (72)	06/12/2012 (51)	27/12/2012 (72)	04/01/2013 (80)
Exp. 1 High VGR	31/01/2013 (58)	16/01/2013 (43)	31/01/2013 (58)	14/02/2013 (72)
Exp. 2	15/01/2014 (64)	06/01/2014 (55)	15/01/2014 (64)	28/01/2014 (77)

Measurements

VGR was monitored weekly from first square (where 50% of plants have squares) to 2 weeks after the last application in the multiple application treatments. Measurements included height and number of nodes from the plant cotyledon to the terminal node. VGR was calculated using Equation 1 where H and N refer to height (cm) and number of nodes, respectively, measured at weekly intervals (1, 2 week), as described by Constable (1992).

$$\text{VGR (cm/node)} = (H2 - H1) / (N2 - N1) \quad \text{[Equation 1]}$$

Measurements before harvest included final plant height, total nodes, number of fruiting branches, number of vegetative branches, number of vegetative fruit, total fruit and % fruit retention. Cotton lint was harvested using a specialised cotton picker used for small plot experiments.

Results and discussion

At flowering, the effects of MC on yield were less at higher VGRs compared with the response measured in conventional cotton that retains less fruit, which is currently used to support industry MC recommendations. In contrast, lower VGR's were more negatively affected by the application of MC than was previously measured.

Final plant height (cm)

In Exp. 1 there were significant increases of over 20 cm in final plant height in the high compared with low VGR treatments. No differences in final plant height were measured between early season single verses multiple MC treatments in Exp 1 and 2.

Final node count

In Exp. 1, the low VGR crop had almost one node more than the high VGR crop. In both experiments there were no differences in the number of nodes between the two early season MC treatments (single and multi-rate), although a significant difference of one extra node was measured in the control.

Final Fruit Retention

In Exp. 1 there was no difference in % fruit retention in the low or high VGR crop types (data not shown). However there were significant differences measured between crop types. The low VGR plots had almost 15% more fruit retention than the high VGR plots. In Exp. 2 (which was only a high VGR crop type), the single early application of MC had increased fruit retention by 5% over the control and multi-rate treatment, which were not significantly different from each other.

Lint Yield

In Exp. 1 the low VGR crop out-yielded the high VGR crop by 1044 kg/ha, which was likely to be associated with the later planting time than from having a high VGR. As can be seen in Figure 1, where there was a significant interaction of the early application MC treatment with crop type. In the low VGR crop, yield was 7% more in the control than both the MC treatments, which were the same. Conversely in the high VGR crop the application of MC treatments increased yield by 11% compared with the control. Again both the MC treatments (single and multi) were not different from each other.

In Exp. 2 (a high VGR crop) there were no significant differences between the early application MC treatments.

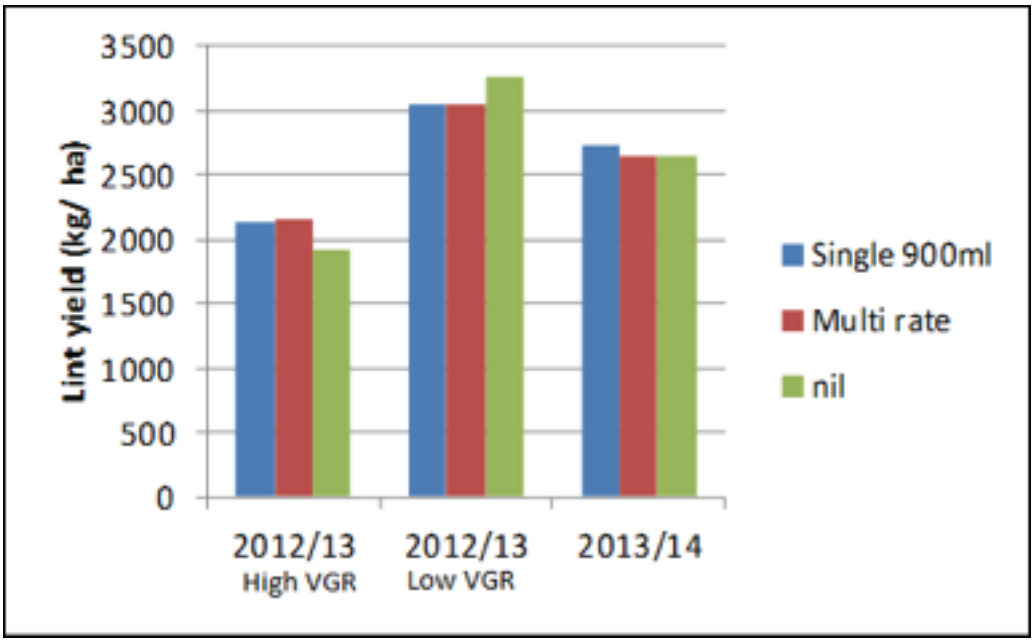

Figure 1. Mean lint yield (kg/ha) for VGR and MC treatments in Exp. 1 (2012/13) (Standard error of the difference 136 kg/ha).

Vegetative Growth Rate (VGR) compared with MC yield response

Figure 2 presents our data along with the original lint yield response curve from Constable (1994) who undertook a similar assessment on conventional cotton varieties. Lint yield increased in response to the application of MC, however the degree of the response differed to that measured by Constable (1994). The effects of MC on lint yield were: less at higher VGRs compared with traditional varieties; and yield of cotton with low VGR at flowering was much less with MC than previously measured.

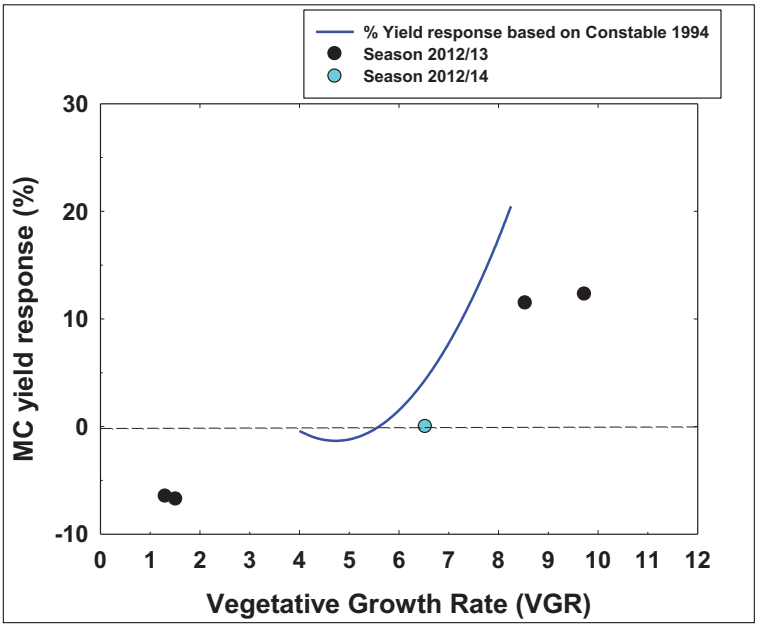

Figure 2. VGR (at flowering) and the corresponding yield response % when MC is applied. The plotted response is the original curve generated by Constable (1994), the black dots are data included from Exp. 1 for the early application treatments and the blue dot is the mean of all treatments from Exp.2.

Conclusions

Our results have shown that in a Bollgard® II crops there are a reasonably good correlation between VGR at flowering and yield response to MC. Therefore monitoring VGR for early season MC requirements should remain a very important component of the decision making process.

While more research is needed across the industry to support these findings (especially for other regions), it does highlight that the use of MC around flowering does require some caution. Additionally this research also supports that Bollgard® II crops are less responsive to MC at high VGRs compared with MC responses measured in conventional cotton varieties, such as by Constable (1994). The recommended VGR threshold of 5.5 cm/node for a conventional cotton crop may need to be increased to 6.5 cm/node for a Bollgard® II crop.

Research is continuing to investigate the use of measuring VGR on crops across a greater range of environments and rates of MC. This is important as the current VGR approach may not be applicable to all environments. For example VGR was inappropriate in tropical Australia (Grundy *et al*. 2012), as cotton has a tendency to produce more vegetative growth than crops grown elsewhere and the current industry VGR recommendations can lead to excessive MC being applied, affecting yield adversely.

Acknowledgments
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Management for premium cotton fibre

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Abstract
Cotton fibre quality is affected by a large number of interacting factors; cultivar, seasonal conditions, crop and harvest management, and ginning. These can all determine whether or not the spinner's requirements are met. With the advent of premium fibre varieties, there may be a need to have tailored management regimes so growers attract the maximum return for production to offset lower lint yields. A large scale field experiment was conducted in Narrabri to establish the value of specific pre- and post- harvest management practices to deliver high quality cotton. The experiment used the cultivars Sicala 340BRF (a premium fibre type) and Sicot 74BRF (popular industry cultivar) grown with two management regimes ('standard' and 'wise' management). The wise management treatment involved targeted irrigations at flowering, a later defoliation (avoiding use of boll opening chemical) and using late season growth regulator to ensure that crop maturity avoided inclement weather. Following harvest, cotton was also subjected to zero and two lint cleaning passages to remove foreign material at ginning. As expected the premium fibre cultivar yielded less and produced fibre of better quality. Under the wise infield management system fibre was longer and was lower in the incidence of fibre entanglements (neps). Extra lint cleaning passages lowered trash content improving quality, however reduced yield and fibre length, and increased neps. While this research demonstrates that there are combinations of pre- and post- harvest management practices that can influence quality without affecting yield, further research is required to establish the relative economic and agronomic benefits of adopting these practices to enhance fibre quality alone.

Key words
Cotton, fibre, quality, management, post-harvest

Introduction

Australian cotton is already purchased for a premium as it meets spinner's requirements on the basis of quality and consistency. Fibre quality is affected by a large number of interacting factors: variety, climate, in-season management, harvesting and post-harvest ginning practices. While some of these factors cannot be controlled, there are many that can. Fortunately the majority of crop management factors which increase/optimise yield will also increase/optimise fibre quality. Indeed with the advent of specific premium fibre varieties there may be a need to have tailored management regimes to ensure that these varieties produce premium quality cotton. Through better understanding of the nature of fibre and the factors that affect its quality, improved cultivars, management for each region's climate, and processing to minimise damage to fibre are all opportunities to improve the quality of fibre delivered to mills.

Since the fibre is primarily cellulose, any influence on plant photosynthesis and production of carbohydrate will have a similar influence on fibre growth. Cell expansion during growth is strongly driven by turgor, so plant water relations (irrigation) will also affect fibre elongation in the period immediately following flowering. Early crop defoliation or leaf removal can cause substantial reductions in fibre micronaire due to the cessation in carbohydrate supply for fibre thickening. Few agronomic or climatic conditions have been shown to consistently affect fibre strength. Any management which delays crop maturity can lead to reduced micronaire and more neps (Bange et al. 2010), as well as lower grades from discolouration and increases in leaf material (Bednarz et al. 2002), all due to exposure of a greater proportion of a crop to unfavourable conditions such as cooler or cloudy weather.

The post harvest ginning process transforms the cotton into a marketable commodity by removing the lint from the seed and removing foreign material. Ginners are faced with often conflicting objectives: the need to maximize gin outturn to increase lint yield for growers; to minimize impact on fibre quality to meet the needs of the spinners; and optimizing gin throughput and operating efficiencies. As the ginning process will impact

on fibre quality (Anthony, 1999), any operation in the gin should be bypassed in an attempt to preserve quality if the cotton does not need specific treatment, a particular process that is a focus of fibre preservation is the use of a different number of lint cleaners (Long et al. 2010).

This paper presents yield and fibre quality results of large scale farming systems experiments will compare ± premium varieties, ± modified agronomy (including changes in irrigation, crop cessation and defoliation management) and ginning ± lint cleaning. Improving the understanding of the links between production, harvest, ginning and textile processing will facilitate better crop management recommendations to ensure Australian cotton exceeds market expectations.

Methods

Cultural Details

A large scale field experiment was conducted at Narrabri NSW Australia to assess practices tailored to deliver better fibre quality. Cultivars Sicot 74BRF and Sicala 340BRF (both CSIRO, Australia) were planted 13 Oct. 2010 and grown with high input management and insect control. Sicot 74BRF is a popular high yielding cultivar, while Sicala 340BRF is a lower yielding (by approx. 6 %) cultivar that has better fibre properties (3% longer and stronger fibres, respectively, and lower micronaire 4.4%) (CSD, 2014). A split plot design with four replicates and 583 m long by 4 m wide (4 rows) plots were used. The main plots were two management treatments ('wise' and 'standard') and sub plots were cultivars. There was an eight row buffer between main plots.

The wise treatment was intended to enhance fibre quality, while the standard treatment used current industry practice. The differences in the wise treatment compared with the standard treatment were as follows: 1. An extra irrigation was applied during flowering to assist in fibre elongation; 2. The growth regulator mepiquat choride was applied (22 Feb 2011) around the time of the estimated average last effective flower date (27 Feb) to assist the crop maturing at the appropriate time to avoid inclement weather at the end of the season; and, 3. Avoiding the early use of harvest aids at the end of the season that cause bolls to open prematurely, thus increasing the risk of lower micronaire cotton and higher nep counts.

At the end of the season (11 Jun 2011) the middle two rows of each plot were harvested using a spindle picker. All harvested seed cotton from each plot was collected and ginned at CSIRO's post harvest cotton research facility in Belmont, Geelong. Seed-cotton from each plot was then subjected to either zero or two lint cleaning passages. Lint cleaning is an additional process undertaken at ginning that aims to further remove trash from cotton.

Measurements and statistics

Once ginning had been completed an estimate of plot lint yields were calculated. During the ginning process lint was sub-sampled (approximately 15 x 20g lots) for each plot and lint cleaning treatment. These samples were then recombined and thoroughly mixed and re-sampled twice, and so ensuring a sampling precision greater than that used commercially for the High Volume Instrument (HVI) testing of fibre. Lint samples were subjected to quality assessment using a HVI 1000 instrument to measure upper half mean length (mm), strength (cN tex^{-1}), and micronaire (no units). Samples were also subjected to testing via an Advanced Fibre Information System (AFIS PRO) instrument to measure total neps (count g^{-1}) and total trash (count g^{-1}). Data was analysed using ANOVA and a split-split plot design, where lint cleaning treatments was the sub-sub plot.

Results and discussion

For yield, Sicot 74BRF yielded 7% more fibre compared with the premium cultivar Sicala 340BR, which was in line with other yield results for these cultivars (Table 1). There was an interaction between infield management practice and ginning treatment. The wise treatment 2LC had a greater reduction in yield (6.9%) compared with lint cleaning using the standard treatment (5.3%). As expected, lint cleaning greatly reduced yield because a large amount of trash was removed that did not contribute to the weight of baled fibre. For example, lint cleaning reduced AFIS trash by 47% for Sicot 74BRF and by 54% for Sicala 340BRF. The lint cleaning process is also the most mechanically intensive in the cotton post-harvest processing and this was evident by a reduction in fibre length (1.2%) and a 27% increase in total neps. As hypothesised the infield management treatment did not affect yield, but did affect some fibre quality attributes.

Table 1. Effect of cultivar (Sicala 340BRF, Sicot 74BRF), management treatment (wise and standard), and ginning treatment (OLC – no lint cleaning, 2LC – two lint cleaners applied at ginning) on cotton yield and fibre quality traits. Only significant main effects and highest order interactions are shown.

Variable	Ginning Treatment	Sicala 340BRF		Sicot 74BRF	
		Standard	Wise	Standard	Wise
Lint Yield (kg/ha)	0LC	2078	2193	2185	2390
	2LC	1968	2042	2079	2236
LSD (0.05)	Cultivar (C)	68**			
	Ginning Treatment (G)	14***			
	Management (M) x G	234**			
Fibre Length (mm)	0LC				
	2LC	32.37	32.79	31.54	31.92
LSD (0.05)		31.97	32.52	31.03	31.58
	Management	0.19**			
	Cultivar	0.25***			
	Ginning Treatment	0.19***			
Fibre Strength (grams tex^{-1})	0LC	34.94	35.59	32.71	33.23
	2LC	34.19	35.18	32.39	33.56
LSD (0.05)	Cultivar	0.15***			
Micronaire (no units)	0LC	4.30	4.29	4.54	4.49
	2LC	4.21	4.21	4.49	4.41
LSD (0.05)	Cultivar	0.06***			
	Ginning Treatment	0.05**			
Neps (count g^{-1})	0LC	203	196	183	181
	2LC	294	268	256	234
LSD (0.05)	Management	10*			
	Cultivar	15**			
	Ginning Treatment	13***			
Trash (count g^{-1})	0LC	1615	1702	1126	1209
	2LC	723	806	580	651
LSD (0.05)	Cultivar	85***			
	Ginning Treatments	76***			
	C x G	104***			

* Significant at the 0.05 level;** Significant at the 0.01 level;*** Significant at the 0.001 level

The wise management treatment significantly improved fibre length due to additional irrigation during the fibre elongation phase. Fibre elongation is associated with internal plant turgor pressure (Constable and Bange 2007) and this additional irrigation would have assisted in avoiding any stress that may have been encountered during this phase. This effect did not however translate into changes in yield.
As expected the premium cultivar Sicala 340BRF had longer fibres (2.8% longer) than Sicot 74BRF.

Micronaire was not influenced by infield management, which can be attributed to there being little effect of the defoliation treatment (no boll openers) on plants that had probably matured adequately before the application of the treatment. This ensured that fibres had adequate secondary cell wall cellulose deposition (fibre maturity) which influences micronaire (Bange et al. 2010). There were no significant differences between management treatments for micronaire. The significantly lower micronaire result for Sicala 340BRF is attributed to that cultivar being finer or having average fibre perimeter dimensions less than Sicot 74BRF. Lint cleaning affected micronaire because trash in a fibre sample contributes to the resistance of air during the micronaire measurement.

For neps, the longer and finer premium cultivar Sicala 340BRF had a greater propensity to buckle and knot and had 10.8% more total neps compared to the shorter and coarser Sicot 74BRF cultivar. Fibre maturity is also an attribute often reported as being related to neps because thinner cell walls make for fibre that has a greater propensity to break and entangle (Anthony et al. 1988). Here the infield management treatment did not change fibre micronaire (a measure of fibre maturity). In comparison the wise treatment reduced neps by 6% while simultaneously improving fibre length. The reduction in neps is attributed to the wise

treatment also having better length uniformity (consistency of length) and less short fibre (% of fibres shorter than 12.7mm) (data not shown). Shorter and less uniform fibre populations are known to exhibit disproportionately more processing problems including neps. Fibre strength is also related to neps, but in this case there was no infield management effect on strength, although as predicted, Sicala 340BRF fibre was stronger than Sicot 74BRF fibre by 2 cN tex^{-1}.

Conclusion

In these studies there were consistent effects with current knowledge of premium fibre cultivars on yield and fibre quality. In-field management practices studied here did not affect yield but did improve fibre quality. An extra irrigation was required to improve fibre length but this did not improve yield. The economic and agronomic benefit of this practice still needs to be assessed against the improved fibre quality attained.

Additional lint cleaning passages after harvest did not improve either yield or quality. Consequently it is preferable to avoid lint cleaning passages. However, the impact of additional trash on cotton quality is still being assessed. Further research is being undertaken to evaluate these infield and post harvest treatments in other seasons, as well as the impact of these practices on final textile quality.

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Thin oxodegradable film and profile soil water under cotton

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Abstract
Previous studies utilising oxodegradable thin film have shown that seedbed soil temperatures were elevated between 2-4 ^{o}C, and seedbed moisture was conserved under the film compared with bare soil. The issue of film restricting cotton emergence has been resolved by using slit film at planting. It is speculated that thin film may conserve profile soil water for longer than under bare soil, thus conferring some benefit in the early growth of cotton possibly due to better root growth.

This preliminary work followed changes in profile water with and without film at two irrigated (Narrabri and Carrathool) and a dryland (Willow Tree) site. Multi-depth-soil-moisture-sensors installed in the plant line monitored changes in soil water at 10, 30, 50, 70 and 90 cm with the data being logged at three hourly intervals.

Preliminary results indicate that profile water varied both under the film and bare control and over time at all sites, with the profile under the thin film being drier at one irrigated (Narrabri) and wetter at the dryland (Willow Tree) site and wetter at the second irrigated site (Carrathool). There was no difference in plant height, node numbers and open bolls at the end of the season between treatments at all sites. It is yet to be determined if differences in profile water will translate into greater lint yield at picking.

Key Words
Plastic film, Mulch, Irrigated cotton, Dryland cotton

Introduction
Thin plastic film has been used as a mulch to increase soil temperature, conserve soil water and to improve crop establishment for crops such as maize (Li et al. 2014), vegetables (Qin et al. 2014) and cotton (Dai and Dong, 2014).

If the film is impermeable to water, evaporation from soil is reduced which will alter evapotranspiration (ET). There can be an advantage in rainfed situations by conserving available water and improved crop water use efficiency (WUE), which can reduce seasonal variability associated with rainfall (Bu et al. 2013). Under irrigation there is potential to reduce water use and increase WUE (Yaghi et al. 2013), which will be attractive as the price of water increases or security of access to and supply of water decreases.

Little work has been undertaken to assess the benefit of thin film in conserving soil profile water over time. This preliminary research was undertaken to test the hypothesis that thin oxodegradable film could conserve soil profile water under a cotton crop during the growing season.

Materials and Methods
Field experiments were conducted at Narrabri and Carrathool under irrigation and at Willow Tree under rainfed conditions. All experiments compared slotted thin film covered areas with uncovered areas as the control. Two films were used at Narrabri (F1, oxodegradable & F2, certified biodegradable), one at Carrathool (F1) laid in 6 alternate rows and across 24 rows at Narrabri and Carrathool, respectively while the experiment at Willow Tree was a demonstration site with no replication. Fields were planted on 29 September 2014, 22 September 2014, and 4 October 2014 at Narrabri, Carrathool and Willow Tree, respectively with the thin film being placed mechanically on the same day at Narrabri and Carrathool and five days after planting by hand at Willow Tree. Plots were the three rows (1m spacing) by 180 m and 500 m at Narrabri and Carrathool, respectively, and only two rows by 10 m at Willow Tree. Cultivar Sicot 74 BRF was planted on ridges at Narrabri and Carrathool with Sicot 71 BRF being planted on flat ground at Willow Tree.

Multi depth soil moisture sensors (Odyssey, Dataflow Systems) were installed at each site on the same day as the film was laid with the exception being Willow Tree. Sensors were placed in access tubes in oversized augured holes at Narrabri and Carrathool and pushed to depth at Willow Tree. The oversized holes were filled with a soil-water slurry before the access tubes were inserted. This necessitated that the data for the first 7 DAP (Days after planting) being ignored as the soil re-equilibrated. Profile moisture was logged at 10, 30, 50, 70, and 90 cm depths every three hours during the growing season at each site. The sensors were not calibrated for each site, however they were all set-up with the same parameters to ensure that relative differences between treatments would be maintained. Soil water monitoring was unable to be replicated at all sites due to equipment restrictions. The fields were managed by the individual growers at each site.

Results and Discussion

For the Narrabri site the bare control treatment started wetter and continued to be so throughout the season compared to the film treatments (Fig. 1), which contrasts the observations from previous studies (Li et al. 2014, Qin et al. 2014, Dai and Dong, 2014). This was unexpected and most likely due to starting profile water varying across the experimental site. To determine whether the films at this site were effective in conserving profile water the data were made relative to the starting profile water under each treatment (starting soil water subtracted from subsequent readings); this adjusted all treatments to the same starting value (Fig. 2). Although there was variation in profile water during the season the soil profile tended to be wetter from 42-65 DAP under the films (Fig. 2) with treatments being similar until 93 DAP when film 1 began to breakdown and the profile started to dry down. After 109 DAP the soil profile under film 2 was wetter until monitoring ceased, while both film 2 and the bare treatment dried to similar points between irrigations (Fig. 2). Film 2 did not degrade as rapidly as film 1. Irrigations occurred on 1, 24, 66, 83, 106, 116, 128 and 138 days DAP.

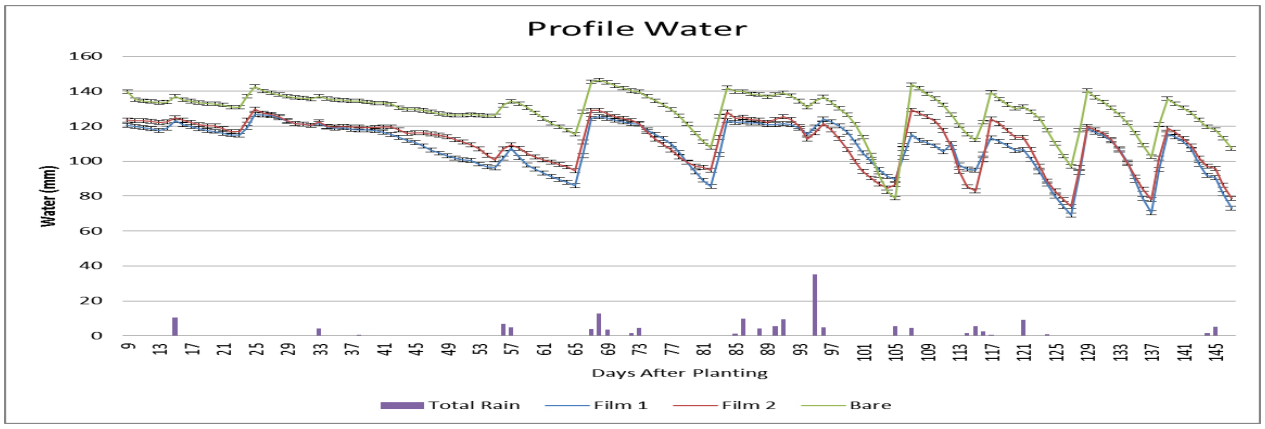

Figure 1. Soil profile water under film and bare treatments at the Narrabri irrigated site 2014-2015 (bars are +/- standard error of daily data)

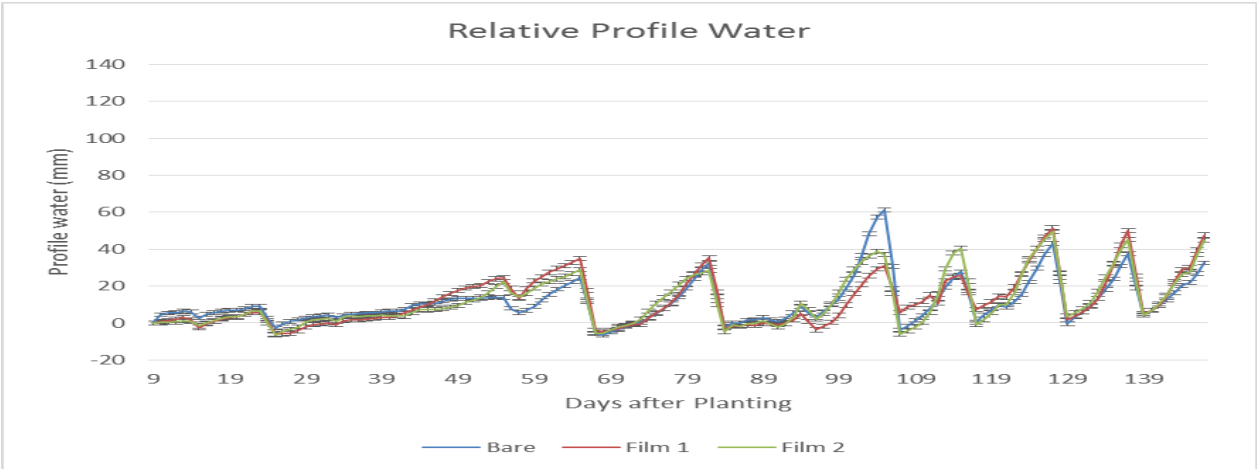

Figure 2. Relative change in soil profile water under film and bare treatments at the Narrabri irrigated site 2014-2015 (bars are +/- standard error of daily data)

At the Carrathool site, the thin film maintained the soil profile wetter though the season compared to the bare treatment (Fig. 3). The bare treatment was wetter after the first irrigation as it took longer for irrigation water to move from the furrows to the plant line under the film. Both treatments came together after subsequent irrigations with the film maintaining a wetter soil profile between irrigations (Fig. 3).

For the rainfed site at Willow Tree, the thin film maintained higher soil profile water compared to the bare treatment over the period of monitoring (Fig. 4). Peaks in soil moisture coincide with rainfall events during the season (data not shown) indicating that the rainfall was effective in replenishing profile water under the film and the bare treatment with the film protecting profile water.

The results indicate that the profile was wetter under the film at the point when monitoring ceased at Carrathool and Willow Tree, while the profile was wetter under film 2 and drier under film 1 at Narrabri due to film 1 breaking down earlier than film 2. In the rainfed system the profile dried down to a greater extent under the bare treatment compared to the film which suggests that water extraction patterns may be different under the two treatments.

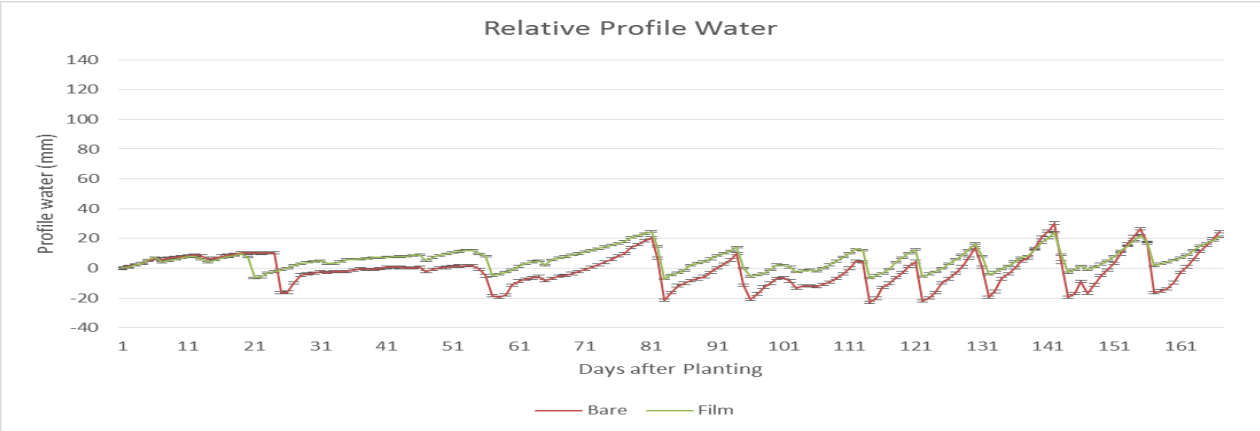

Figure 3. Relative change in profile water under film and bare treatments at the Carrathool irrigated site 2014-2015 (bars are +/- standard error daily data)

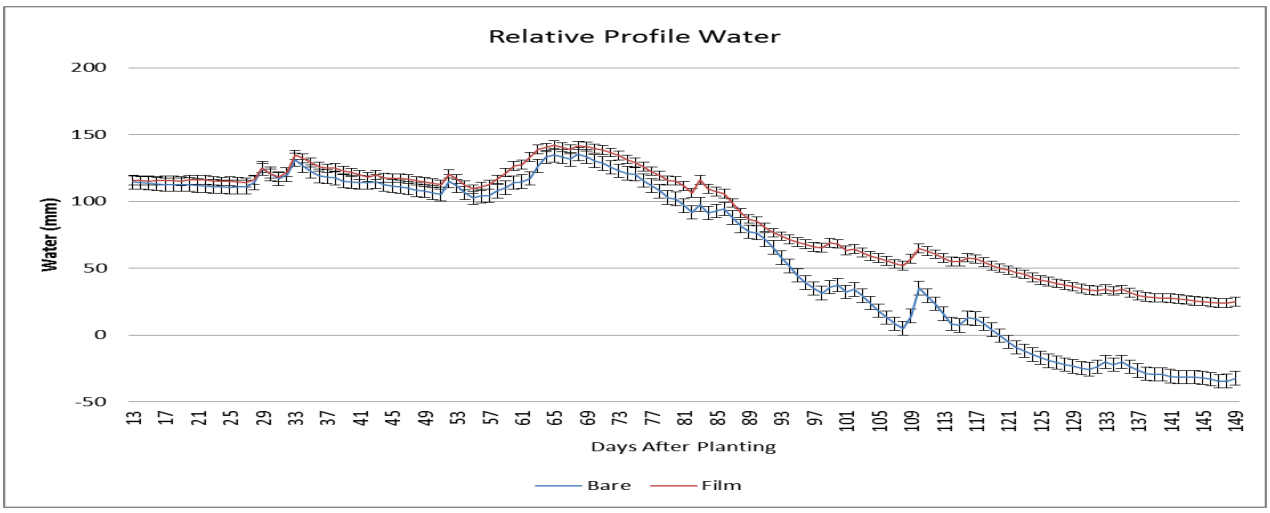

Figure 4. Relative change in profile water under film and bare treatments at the Willow Tree dryland site 2014-2015 (bars are +/- standard error of daily data)

Conclusions

Thin oxodegradable thin film shows potential to conserve soil profile water during the season under both irrigation and rainfed cotton systems. There were differences between irrigated and rainfed and between bare and film, which reflect environmental conditions at each site. There is a need to repeat the experiments over several seasons to be able to quantify the effect in the long-term. This will require further resources for replicated monitoring of profile water.

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Improved temperature for maize growth using clear polymer film

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Abstract
Clear polymer films (CPF) are used as a supporting technology for maize production in a number of high latitude countries to promote higher soil and air temperatures during the early stages of crop growth. By providing frost protection and promoting early development, crops can be sown earlier and hence mature within the short growing season. A research program is currently underway in Australia to develop a degradable form of CPF suitable for use in broad-acre crop production. This paper reports on findings from a 12 month field trial conducted in southeast Australia into the effect of film on the growing climate under film. Daily temperature increases under the film barrier were strongly influenced by seasonal variations in day length, solar radiation intensity, soil water content and condensation build-up on the underside of the film, and can become supra-optimal for crop growth. Relationships between key ambient and headspace climate variables will be used in ongoing crop physiology studies and for assessing the seasonal and regional suitability of CPF technology.

Key words
Temperature stress, Zea mays.

Introduction
Within many regions of southern Australia, irrigated maize (*Zea mays*) production is limited by a combination of cold spring temperatures and summer heat stress. Maize germination and crop establishment occurs slowly and sporadically in soils below 12 °C (Bollero *et al*., 1996) and the crop is especially susceptible to frost damage during these early growth and the later silking stages (Sánchez *et al*. 2014). For this reason, maize is not planted until soil temperatures reach 14°C, which can delay sowing until early November in many regions of Tasmania, Victoria and southern NSW (Pembleton and Rawnsley, 2012). Southern Australian maize planted in late spring is more susceptible to heat stress from high summer temperatures during silking and anthesis. Heat stress during this early period of reproductive development increases pollen and ovary sterility and increases zygote abortion, reducing the yield potential of grain (Barnabas et al., 2008). The long duration of silage maize crops can also lead to frost damage during crop maturation in autumn, further reducing crop quality (Pembleton and Rawnsley, 2012).

Current management strategies for reducing cold and heat stress risk in maize include the manipulation of sowing time, varietal selection and through strategic irrigation. Another potential management strategy is through the use of degradable clear polymer film (CPF). CPF is made from a thin layer of impervious and stretchable petroleum-based polyolefin or bio-derived materials. Strips of this material are installed over a newly sown crop and the edges buried on either side with soil, where it increases enclosed air and soil temperatures by trapping outgoing terrestrial radiation (Miller and Bunger 1963), recycles evapotranspiration (ET) losses back to the soil (Dubois 1978), and captures and concentrate soil and plant CO_2 and O_2 emissions. The film remains intact for a period determined by the chemical composition of the film and the environmental conditions. Once the film breaks down (typically 30-50 days after sowing) the crop continues to grow normally. The higher temperatures under the film reduce early season cold stress and enable earlier sowing and faster crop growth (Walker, 1969). The subsequent advancement of flowering and crop maturation may also reduce heat stress risk at flowering and late season frost risk. CPF is currently used in northern Europe and Canada to promote faster and higher rates of maize establishment, and increased productivity and earlier maturation (Orzolek *et al*. 2000).

This paper reports on findings from a Tasmanian study into the growing environment under CPF and how the use of CPF may influence maize planting dates, as well as any seasonal limitations to the use of the CPF due to supra-optimal temperatures and excessive heat accumulation.

Materials and methods

A trial site was established in August 2013 near Cambridge (42.79°S, 147.42°E) in southeast Tasmania. Strips of clay soil (~4 m long X 2 m wide) to be covered with film were cleared of weeds and tilled uniformly in a north/south orientation to a depth of ~30 cm and irrigated to field capacity. The soil was shaped into a mound and covered with strips of UV stabilised, clear polyethylene propagation film (3 m long X 1.2 m wide X 10 µm thick) manufactured by Integrated Packaging Pty Ltd. Melbourne. The edges of the film overlay were buried to a depth of 15cm to create a sealed headspace.

Atmosphere/climate sensors were positioned under and adjacent to the film to capture trends in ambient and confined headspace temperature, solar radiation and relative humidity. Temperature and relative humidity were measured using a combined sensor (Campbell Scientific CS 215 probe) housed inside a louvered radiation shield. Ambient temperature and relative humidity were measured at ground level and at a height of 1.2 m to replicate the standard design of Bureau of Meteorology weather stations to enable direct comparison between headspace and ambient data, and for comparison against historical climate data (BOM, SILO databases). Solar radiation was measured with an Apogee pyranometer (SP110) covering the short-wavelength range of 360 to 1120 nm and a 180° field of view. The headspace pyranometer was placed 2 cm below the film in all treatments. Temperature, radiation and relative humidity were measured every 10 minutes and stored in a Campbell Scientific CR200X logger from which data was downloaded remotely via wireless access. The trial was run over 12 months (i.e. August 2013 to July 2014) to capture a wide range of ambient climate conditions.

Results

The effect of CPF on heating and cooling processes fundamentally altered the daily temperature profile of the crop growing environment. Daily temperature fluctuations from solar heating occurred rapidly within the CPF-enclosed treatment, elevating maximum headspace temperatures by 15-40 °C above ambient environmental temperatures over the durationn of the trial. Headspace temperature increases were lowest during August and greatest during November, with maximum daily temperatures occuring within 5 hours of sunrise. In contrast, daily heating occured slower within the control treatment exposed to ambient conditions, requiring 8-9 hours to elevate daily surface temperatures by only 9.3 ± 3.1 °C. These daily fluctuations in temperature within CPF-enclosed headspaces correlated strongly with daily variations in incident solar radiation ($r = 0.523$, $n = 108$, $p < 0.001$).

These alterations to the rates of headspace heating and cooling altered the frequency and duration that headspace temperatures remained within temperature thresholds considered physiologically important for maize growth. For the control treatment, more than 30% of days between August 14th (day 227) and December 1st (day 336) failed to exceed 14 °C and enter the maize exponential growth response window described by Walker (1969) (Figure 1). Similarly, only 4.5% of days exceeded 23 °C (Figure 1), which marks the beginning of the optimal thermal kinetic window for maize growth (Mahan *et al*. 1990). In contrast, for the same period under CPF, temperatures exceeded 14 °C on all days, and exceeded 23 °C recorded on 91% of days. The application of the CPF-treatment also reduced the incidence and severity of sub-zero (frost) temperatures.

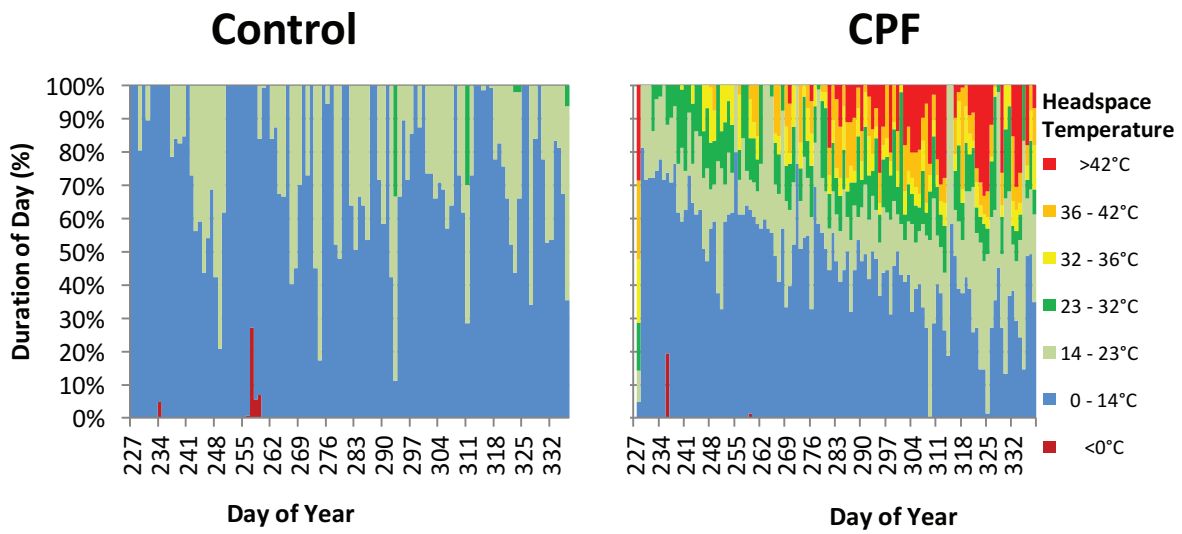

Figure 1 Proportion of 24 hour period where headspace temperatures were below, within and above the optimal 23-32 °C thermal window for maize growth described by Mahan *et al.* (1990). Exposure to temperatures within the optimal temperature range and the exponential growth response window (14-23 °C) described by Walker (1969) were greater within the CPF-enclosed treatment increased seasonally. Exposure to supra-optimal (32-36 °C), acutely supra-optimal (36-42 °C) or potentially fatal temperatures (>42 °C) also increased in response to seasonal changes.

Discussion

Over the winter/spring period, the CTF film increased temperatures in the headspace to levels that would support maize establishment and productive growth and development. Over this period, headspace temperatures were within the optimal range for maize growth and development, 23-32 °C (Mahan *et al*. 1990) and the exponental growth response range of 14-23 °C (Walker 1969) for several hours each day. Without the protection of this insulating layer of CPF, headspace temperatures within the growing environnment were much lower than CPF enclosed films throughout the observation period, and on many days only a small percentage of each day exceeded the minimum cardinal temperatures required for leaf elongation (7.3 ± 3.0 °C), stem growth (10.9 ± 1.4 °C) and root growth (12.6 ± 1.5 °C) described by Sánchez et al. (2014). Due to the close proximity of these minimum cardinal values to maximum daily temperatures throughout this season, even small fluctuations in daily temperature maxima are likely to have a signficant influence upon the duration and efficiency of plant biomass production (Walker, 1969). In contrast, temperature conditions present beneath CPF film enable a more efficient and signficantly extended window for conversion of incident solar radiation into biomass production and plant development during this seasonal period (Mahan *et al*. 1990).

Inadequate heat dissipation and excessive heat accumulation during spring and summer months were also identified as potential issues for CPF-supported maize production within Australia. Over the period from August 14th to December 1st in this trial, 73% of days experienced headspace temperatures that were considered supra-optimal (32-36 °C) or acutely supra-optimal (36-42 °C) underneath the CPF film, and temperatures exceeding the lethal temperature threshold for maize (42 °C, from Birch *et al*. 1997) were recorded on 40% of days. Daily temperatures in excess of 32 °C were first observed during early September and increased in frequency, severity and duration in response to rapid seasonal changes in day length, solar energy intensity, ambient air temperatures and reductions in cloud cover density (Miller and Bunger, 1968). In regions with warm spring temperatures and a low incidence of spring frosts, such heat stress may be alleviated by either physical removal of the film or degradation of the film layer during early spring. Within colder regions where seasonal frost risks are higher and ambient conditions are less favourable for growth, removal of this film layer is likely to elicit an acute cold-shock response and expose early crops to potentially fatal environmental conditions (Sánchez *et al*.,2014). In these circumstances, the use of macro- or micro-perforated CPF films may be utilised to aid heat dissipation and limit temperature extremes without exposing the enclosed plants to frosts and other damaging conditions.

Conclusion

By enclosing the growing environment beneath a CPF membrane, atmospheric heat losses can be reduced to minimise the impacts of crop cold stress upon maize seed germination, crop establishment and vegetative development during early-season growth. Within cold-limited production areas, use of CPF technology may enable the early establishment and growth of maize and other temperature-limited crop species during late winter and spring, enabling the growing season length to be signficantly extended. Simple modification of the technology may also facilitate wider seasonal usage and reduce the issues associated with excessive heat accumulation.

Acknowledgements

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Drivers of high-yielding irrigated canola production

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Abstract
Canola has a sound fit in irrigated agricultural systems despite traditionally being a dryland crop and there is potential to increase the area sown by 25% if yield and profitability is improved. Varieties with superior performance in dryland systems may not be the highest yielding varieties in irrigated systems. The effect of variety and agronomic management on irrigated canola was investigated in six trials located throughout south-eastern Australia – Murrumbidgee, Murray Valley, Lachlan, north-west Victoria, south-east South Australia and Tasmania. Canola variety had a significant effect on grain yield at both Murrumbidgee trial sites (Leeton and Coleambally). At Leeton, 45Y88 (CL) was the highest yielding variety (4.18 t/ha) followed by Hyola 50 (4.17 t/ha) and AV Garnet (3.99 t/ha). At Coleambally, Hyola 50 again performed well yielding the highest, followed by Hyola 577CL and 45Y88 (CL). Variety by time of sowing interaction also had an effect on grain yield. At Leeton, Hyola 50 and 45Y88 (CL) had higher yields at the earlier time of sowing (9 April). In contrast, ATR Bonito and Hyola 577 (CL) achieved higher yields when sown later (24 April). AV Garnet yields were stable over the two sowing times.

Key words
Irrigated, canola, variety, agronomy, high yielding, winter cropping

Introduction
Recent industry research identified significant potential for increased production and profitability of irrigated canola (McCaffery 2006). The 'Southern irrigated cereal and canola varieties achieving target yields' project aims to increase irrigated canola and cereal production in the irrigated agricultural regions of south eastern Australia. This will be achieved by improving grower and adviser knowledge of high yielding canola varieties for irrigated systems and specific agronomy management to improve production, water use efficiency and profitability.

The first of three seasons of trials as part of the project was conducted in 2014. A further two years of trials will be conducted to validate these initial findings and develop recommendations in the form of best management practice guides and variety specific agronomy packages (VSAPs). Similar trials are being replicated throughout the irrigation areas of south eastern Australia.

Methods
The two variety and agronomic management experiments were conducted at two locations in the Murrumbidgee Valley – Leeton and Coleambally (Table 1). The Leeton trial evaluated the effect of variety, time of sowing (TOS) and plant population on grain yield. The experimental design had variety and population nested in TOS with three replicates. A list of varieties is shown in Figure 1. Times of sowing were 9 and 24 April 2014, with low (30 plants/m^2) and high (50 plants/m^2) plant populations. A total of 250 kg/ha N was available at the Leeton trial site – 53 kg N/ha was present in the soil just prior to sowing, 102 kg N/ha was applied at the time of sowing, 50 kg N/ha was applied at visible bud and approximately 45 kg N/ha was mineralised during the season.

The Coleambally trial evaluated the effect of variety and nitrogen (N) management on grain yield. The trial was a randomised block design with three replicates. A total of 145 or 245 kg N/ha was available at the Coleambally site (depending on which nitrogen treatment was applied). The low (50 kgN/ha), medium (100 kg N/ha) and high (150 kg N/ha) N treatments had all nitrogen applied at sowing. The split N treatment had 50 kg N/ha applied at sowing and another 50 kg N/ha applied at visible bud. Data for both trials were analysed using Genstat 17th edition.

Table 1. Leeton and Coleambally trial site details.

	Leeton	Coleambally
Soil type	Self-mulching medium clay	LightHeavy red clay
Previous crop	Barley (2013)	Wheat (2013)
Irrigation	Autumn pre-watering – 2.2 ML/ha Three spring irrigations – 2.8 ML/ha Total – 5.0 ML/ha	Autumn watering-up – 1.0 ML/ha One spring irrigation – 1.2 ML/ha Total – 2.2 ML/ha
Sowing date	TOS 1 9 April 2014 TOS 2 24 April 2014	29 April 2014
Row spacing	300 mm	300 mm
Herbicides	Verdict™ at 100 mL/ha (by boom) Lontrel™ at 100 mL/ha (by boom)	Verdict™ at 100 mL/ha (by boom) Lontrel™ at 100 mL/ha (by boom)
Harvest date	TOS 1 12 November 2014 TOS 2 17 November 2014	6 November 2014

Results

Variety (both sites)

Variety had a significant effect on grain yield at both trial sites. At Leeton, 45Y88 (CL) was the highest yielding variety followed by Hyola 50 and AV Garnet, all yielding over 4 t/ha. The lowest yielding varieties were 43C80 (CL), Victory V3002 and 44Y84 (CL) which yielded 3.24 t/ha, 3.28 t/ha and 3.31 t/ha respectively (Figure 1).

At Coleambally, the highest yielding variety was Hyola 50 (2.76 t/ha) followed by Hyola 577CL (2.56 t/ha) and 45Y88 (CL) (2.54 t/ha). The lowest yielding varieties were ATR Gem, Hyola 450TT and ATR Bonito which yielded 1.77 t/ha, 1.93 t/ha and 2.00 t/ha respectively. Hyola 50, 45Y88 (CL) and AV Garnet were in the top four grain yielding varieties at Leeton and Coleambally.

Variety affected grain oil content at both sites. At Leeton, the highest oil yielding varieties were AV Garnet, 44Y84 (CL), 45Y88 (CL) and Hyola 50. The same four varieties were in the top five oil yielding varieties at Coleambally.

Variety significantly affected plant establishment and normalised difference vegetation index (NDVI) at both trial sites (data not shown) but these measurements did not have a correlation with grain yield. Variety also affected lodging and harvest index at the Leeton site (not measured at Coleambally). At Leeton, Hyola 450TT had the highest varietal lodging of 4.4 when measured on 23 October followed by Hyola 559TT with 1.6 (0 – no lodging; 9 – complete lodging). In addition, ATR Bonito had the highest harvest index (0.43) followed by Hyola 559TT (0.42) and AV Garnet (0.40).

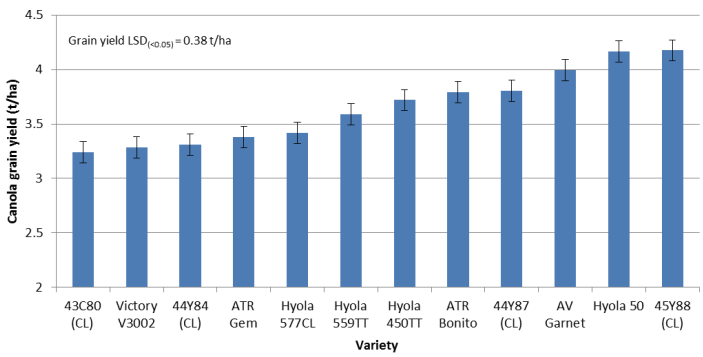

Figure 1. Canola grain yield of varieties averaged across all time of sowing and plant population treatments at Leeton 2014.

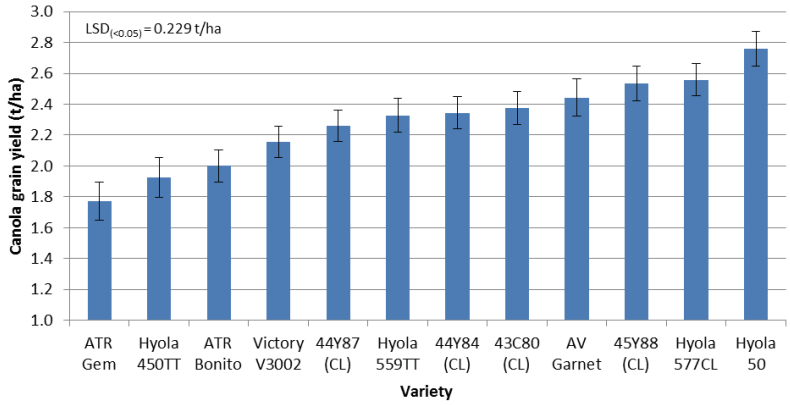

Figure 2. Canola grain yield of varieties averaged across all nitrogen treatments at Coleambally 2014.

Time of sowing (Leeton)

Time of sowing (TOS) showed no effect on grain yield when averaged across all varieties. This is likely due to TOS1 having obvious signs of frost damage and therefore reduced grain yield potential, while TOS2 had no frost damage.

However, there was a significant variety by sowing time interaction at Leeton. Four of the top six yielding varieties 45Y88 (CL) (1), Hyola 50 (2), 44Y87 (CL) (4) and Hyola 450TT (6) had higher yields at TOS1. In contrast, ATR Bonito had higher yields at TOS2, and AV Garnet had stable yields across the two sowing times. All varieties in the lower yielding bracket (7–12) yielded higher in TOS2 (Figure 3).

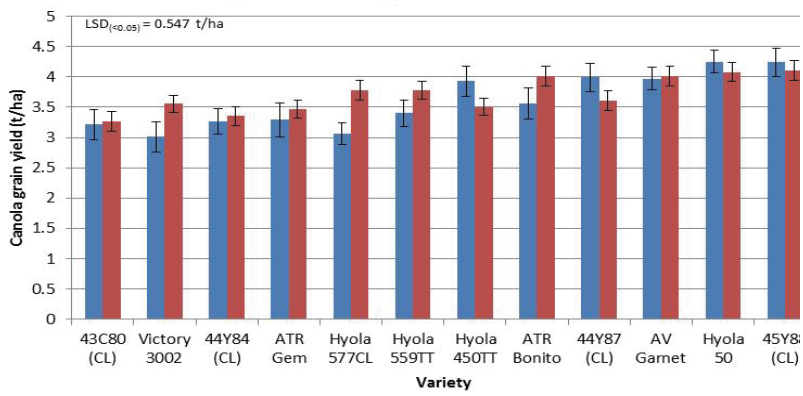

Figure 3. Canola grain yield for varieties at each time of sowing at Leeton 2014.

Plant population (Leeton)

Plant population did not have a significant effect on grain yield.

Nitrogen management (Coleambally)

Nitrogen management demonstrated no significant effect on grain yield.

Conclusion

These canola trials demonstrated that varietal selection is a major driver of achieving high yields. At Leeton, 45Y88 (CL), Hyola 50 and AV Garnet had the highest grain yields. Varieties 43C80 (CL), 44Y84 (CL), Victory V3002 and ATR Gem had low yields irrespective of time of sowing or plant population. Time of sowing did not affect grain yield, potentially due to severe frost events at flowering time of the early sown treatments. Higher plant population reduced oil content whilst having no yield response. These results need to be considered carefully as individual varietal results show variable responses to plant population.

At Coleambally, Hyola 50 and Hyola 577CL had significantly higher grain yields than all other varieties. 44Y84 (CL), Hyola 50, AV Garnet and Victory V3002 had the highest oil contents.

These results represent the first of three years' data. A further two years of trials will be conducted in 2015 and 2016 to validate these results and develop varietal and agronomic recommendations.

Acknowledgements
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Maize (*Zea mays* L.) productivity as influenced by sowing date and nitrogen fertiliser rate at Melkassa, Ethiopia: parameterisation and evaluation of APSIM-Maize

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Abstract

Crop modelling can assist in exploring the production risks and the yield uncertainty associated with rainfall variability but requires empirical data suitable for model testing within a specific system and environment. To parameterise the crop simulation model APSIM-Maize, a field experiment examining a medium maturing maize cultivar sown on two dates and grown at two nitrogen (N) fertiliser rates (0 and 100 kg N ha^{-1}) was conducted at Melkassa, Ethiopia. Model performance was evaluated against six independent datasets from the same site. APSIM-Maize simulated crop phenology, leaf area index, and biomass well for both sowing dates. The model showed acceptable performance in simulating grain yield in most cases. However, at the late sowing date and high N supply, the model over-estimated yield by 37%. The model realistically captured variation in soil water dynamics as indicated by a RMSE of 0.039 mm mm^{-1}. Evaluation of the parametrised model against independent data showed that it was able to reasonably simulate various crop responses including date of silking (RMSE=1 d), date of physiological maturity (RMSE=1.50 d), grain yield (RMSE=0.39 t ha^{-1}), and biomass production (RMSE=0.48 t ha^{-1}) for maize grown at different sowing dates (between June and July) and N application rates (up to100 kg N ha^{-1}).The results showed that APSIM-Maize is credible and can be used for scenario analyses of maize systems in semiarid environments of Ethiopia.

Key words

Crop simulation modelling, Ethiopia, maize, model evaluation, model parameterisation

Introduction

In dryland regions of Ethiopia, fluctuations in annual production are high due to large inter- and intra-annual rainfall variability (Kassie et al., 2013). Maize is the major crop, and plays a significant role in the livelihoods of smallholder farmers (Biazin & Stroosnijder, 2012). Maize yield in the region is approximately 1.5 t ha^{-1}, compared to the national average yield of around 2.2 t ha^{-1} (Bogale et al., 2012). The uncertainty associated with rainfall variability is a major concern for resource-poor farmers, as management options are severely limited (Kassie et al., 2013).

Crop modelling offers an effective way to understand and analyse the consequences of management options under variable climatic conditions. For example, the Agricultural Production Systems Simulator (APSIM; Keating et al., 2003) has been used successfully to simulate maize growth and development for a wide range of climatic conditions (Robertson et al., 2005; Fosu-Mensah et al., 2012; Archontoulis et al., 2014) and management practices (Fosu-Mensah et al., 2012; Kamanga et al., 2014). However, APSIM has had limited use in Sub-Saharan Africa due to the scarcity of suitable input data for model parameterisation, testing, and application (Whitbread et al., 2010).

Data are required to parameterise the model for a new set of conditions including new cultivars (e.g. photo-thermal response) and environments (local soil and climate), and for subsequent model testing to ensure the credibility of model performance. A field experiment was conducted at Melkassa in the Central Rift Valley of Ethiopia to obtain a comprehensive crop and soil data set for a maize system typical to the study region. The objectives of this study were to (i) parameterise APSIM-Maize using phenology, grain and biomass yield, and soil water data from a field experiment specifically designed for modelling purposes, and to (ii) evaluate the capabilities of APSIM-Maize to simulate maize systems in the semi-arid study environment.

Methods

Data from the field experiments conducted at the Melkassa Agricultural Research Centre (8º24' N, 39º12' E, 1550 m elevation) were used for both parametrising and evaluating APSIM-Maize. The location has a semi-arid, tropical climate with a weakly bi-modal rainfall distribution, an average annual rainfall of 820 mm, and a mean annual temperature of 21.2°C (1977-2012). Daily temperature and rainfall were recorded at a local weather station. Daily solar radiation data were available from the NASA POWER database (Stackhouse, 2010). In 2012, a medium maturing maize cultivar (cv. *Melkassa-2*) was sown on 6 July (SD1) and 20 July (SD2). Nitrogen fertiliser was applied as urea at two rates: 0 kg N ha^{-1} and 100 kg N ha^{-1}. Sowing dates were later than the recommended cut-off date of end of June due to late rains. The experiment was irrigated at around silking (i.e. flowering). The dates of key phenological events were recorded, and total above-ground biomass and the leaf area index (LAI) were measured three times during the season. At final harvest, number of grain per head, grain weight and yield was determined. Soil characteristics including bulk density, soil organic carbon, pH, C: N ratio, soil water, and nitrate N ($N\text{-}NO_3$) were determined at six soil depths (0-0.15, 0.15-0.30, 0.30-0.60, 0.60-0.9, and 0.90-1.2 m) prior to the establishment of the experiment. Soil water was measured at one to two week intervals throughout the cropping season from the soil depths as specified above. Following parameterisation, model performance was evaluated against six independent data sets from experiments conducted between 2006 and 2012. These experiments had assessed crop phenology, yield and biomass of cv. *Melkassa-2* at different sowing dates (between June and July) and N application rates (up to 100 kg N ha^{-1}).

The APSIM model (version 7.5), which included the APSIM-Maize, SoilWater, SoilN, and SurfaceOM modules, was used in this study. Important parameters for SoilWater and SoilN are presented in Figure 1. With the use of crop, soil, weather and management data obtained from the field experiment, APSIM was used to simulate silking and maturity dates, soil water dynamics, leaf area index (LAI), grain yield, and biomass, which were subsequently compared with observed data. Model accuracy was assessed using the root mean square error (RMSE) and the coefficient of determination (r^2).

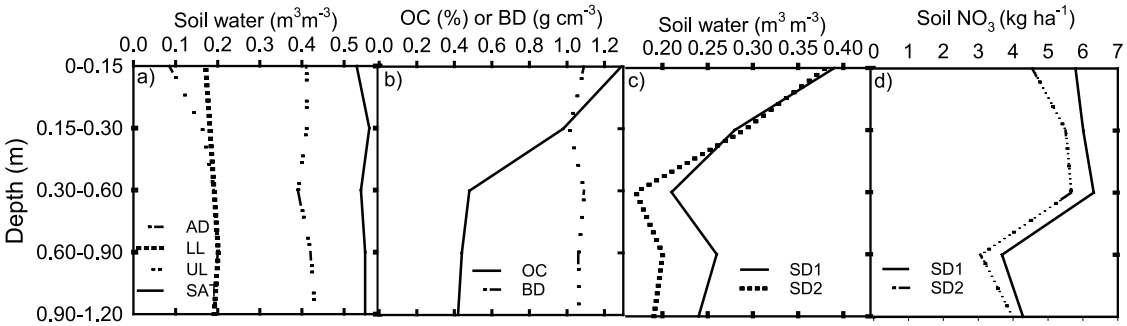

Fig. 1. Soil characteristics at Melkassa: (a) lower (LL) and upper limit (UL) of plant extractable soil water, saturated (SAT) and air-dry (AD) soil water content; (b) organic carbon content (OC) and bulk density (BD); (c) initial volumetric soil water and (d) initial N-NO3 for the maize sown on 6 July (SD1) and 20 July (SD2), 2012.

Results and discussion

Cultivar specific parameters

Cultivar parameters (Table 1) were determined using the experimental data of 2012. The combination of parameter values in Table 1 resulted in the best possible fit (less than two days difference between the observed and simulated dates of silking and maturity).

Table 1. Parameters used to simulate cv. *Melkassa-2.*

Parameters	Values
Thermal time from emergence to end of juvenile stage (°Cd)	230
Thermal time from end of juvenile to floral initiation (°Cd)	0
Thermal time from flag leaf to silking (°Cd)	10
Thermal time from silking to start of grain-filling (°Cd)	160
Thermal time from silking to physiological maturity (°Cd)	730
Maximum kernel number per ear	440

Soil water dynamics

The model reproduced the temporal variation in soil water contents observed in 2012 well. For example, the large reduction in volumetric soil water due to lack of rainfall at about 100 days after sowing was well captured. The RMSE was 0.039 mm mm^{-1} and r^2 was 0.86 (Fig. 2).

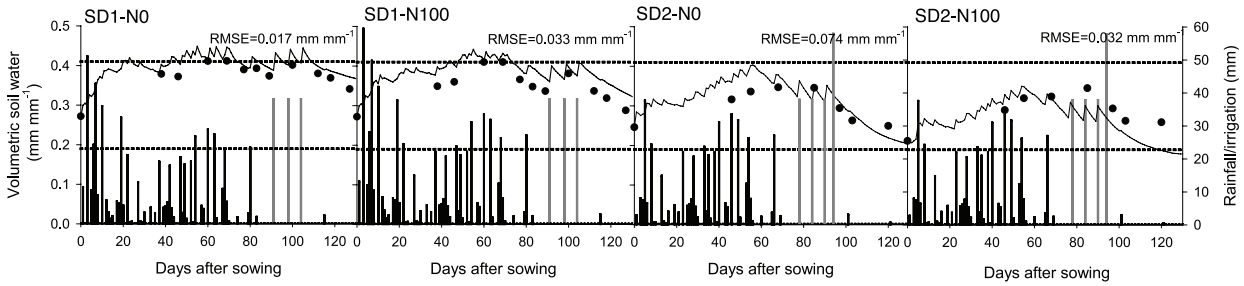

Fig. 2. Simulated (lines) and observed (symbols) soil water content for the whole soil profile (0-1.2 m) for earlier- (SD1: 6 July 2012) and late-sown (SD2: 20 July 2012) maize grown at two nitrogen rates (N0: 0 kg N ha-1; N100: 100 kg N ha-1), Melkassa. The plant available soil water capacity is given between the dotted lines. Bars represent daily rainfall (black) and supplemental irrigation (grey). The r2 ranged from 0.77 to 0.94.

Biomass, grain yield and LAI

In 2012, late-sown maize had received 42% less cumulative rainfall around silking than the earlier-sown crop. This was associated with an average yield reduction of 42% in the late-sown compared to the earlier-sown crop. There was no yield benefit from adding fertiliser N to late-sown maize. However, when maize was sown earlier the application of 100 kg N ha^{-1} increased the grain yield by 39% and total above-ground biomass by 47% compared with the unfertilised crop. Simulated biomass yields were 12-27% lower than observed except for the late-sown maize fertilised with 100 kg N ha^{-1}, where the biomass yield was accurately simulated (Fig. 3). Grain yields were accurately simulated for unfertilised maize, and over-estimated by 11-37% when 100 kg N ha^{-1} were applied. The simulated and observed values for seasonal LAI corresponded reasonably well for both sowing dates. The LAI values increased steadily and approached a peak between 60 and 70 DAS, which is just before flowing. This was well reproduced by the model.

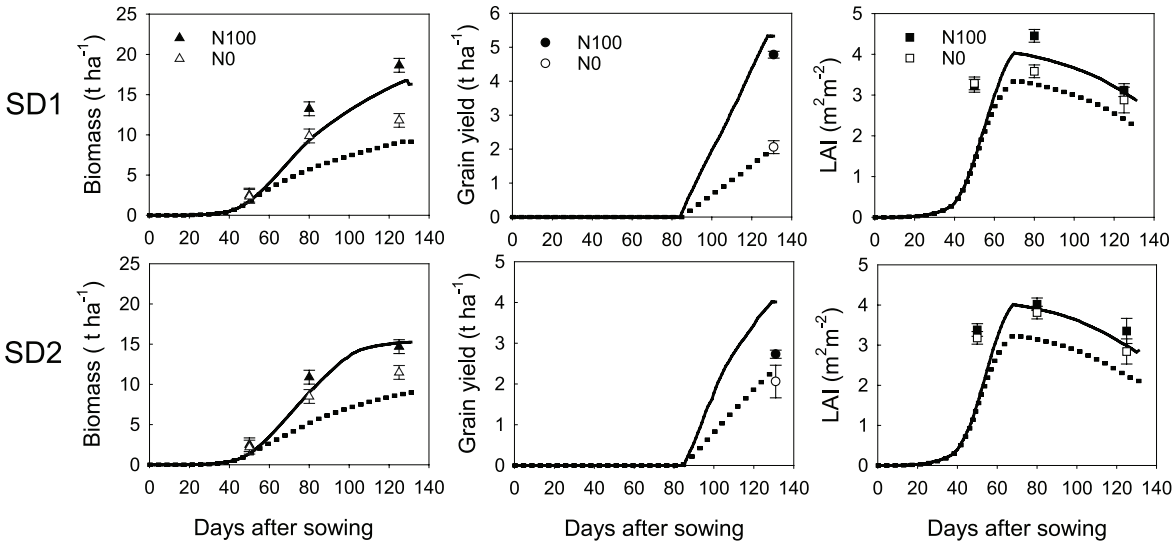

Fig. 3. Comparison of simulated (lines) and observed (symbols) biomass, grain yield, and LAI of earlier- (SD1: 6 July 2012) and late-sown (SD2: 20 July 2012) maize (cv. *Melkassa-2*) grown under two rates of fertiliser nitrogen (N0: 0 kg N ha-1; N100: 100 kg N ha-1) at Melkassa, Ethiopia. Vertical bars represent the standard error of means.

Model evaluation

When tested against independent data, phenological development of cv. *Melkassa-2* was reasonably well simulated, with a RMSE of less than 2 days and an r^2 of 0.89 for days to maturity and 0.80 for days to silking (Fig. 4). Given that these experiments were not designed for model testing, the performance of the model was acceptable in terms of grain yield and biomass production. There was an acceptable to fairly good

agreement between the measured data and simulated values, with r^2 values of 0.66 for biomass and 0.68 for grain yield.

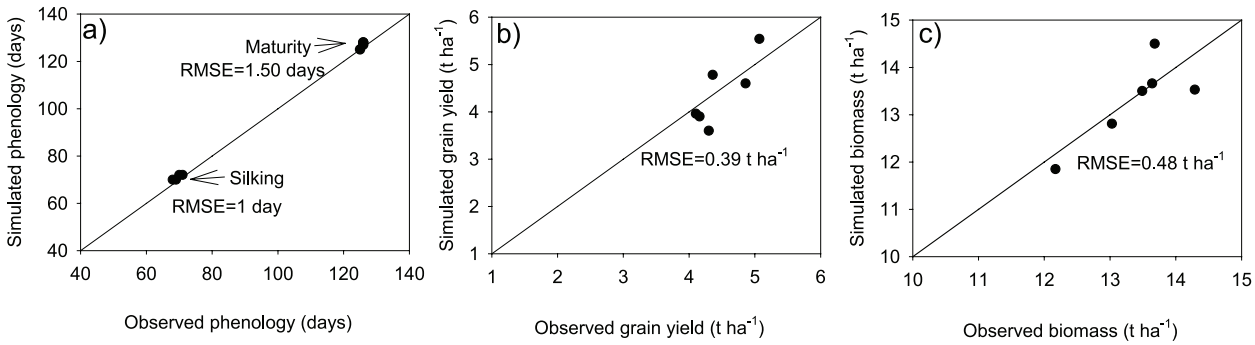

Fig. 4. Comparison of observed and simulated results for (a) days to silking and physiological maturity; (b) grain yield; and (c) biomass of cv. *Melkassa-2* from experiments conducted in 2006-2012 at Melkassa, Ethiopia. The 1:1 fit (y=x) is represented by diagonal lines.

Conclusion

The study showed that APSIM-Maize is able to adequately simulate crop phenology, grain, and biomass yield, as well as the soil water dynamics in the semi-arid study environment. Therefore, APSIM-Maize can be used for scenario analysis to explore management options and resource-use to improve maize productivity in smallholder farming systems of Ethiopia.

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What are the effects of chlormequat and trinexapac-ethyl alone or in combination on lodging, height and yield of winter wheat in Tasmania?

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Abstract
In the High Rainfall Zone (HRZ) irrigation and high rates of applied nitrogen fertiliser may increase the risk of lodging in winter wheat. Crop lodging can limit crop productivity through interfering with water and assimilate supply to the developing grain. Lodging can also interfere with harvest ranging from slowing harvest operation through to total crop loss when lodging is severe. Plant growth regulators (PGRs) mimic or alter production of plant hormones and thus regulate plant growth and development and are used as an insurance measure against lodging. In some instances, PGRs have been reported to increase yield irrespective of whether lodging has occurred. Experiments were conducted on winter wheat cvs. Brennan and Revenue over four seasons (2009-2012) in northern Tasmania. Crops were treated with varying rates, combinations and timings of chlormequat (CCC) and trinexapac-ethyl (TE). Experiments evaluated the individual and combined effects of these two PGRs on height and grain yield. PGRs treatments reduced height in most years, for example in 2012 the combined treatment of CCC and TE applied at early stem elongation had the greatest height reduction, decreasing plant height by 17% compared with the control. No lodging occurred in any year. PGRs increased yield in some years, for instance in 2012, CCC applied at mid tillering and early stem elongation increased yield by 7.5 and 4.1% respectively compared with the control. The results indicate that both TE and CCC alone and in combination can decrease lodging risk and in some seasons PGRs may increase yield.

Key words
Plant growth regulators, cereals, yield components

Introduction
Lodging of winter wheat can increase cost of production by directly affecting yield and increasing costs by reducing harvest-ability of the crop. The plant growth regulators (PGRs), chlormequat (CCC) and trinexapac-ethyl (TE) have been found to decrease height, increase stem diameter (Tolbert 1960) and strength (Zagonel and Fernandes 2007), thereby reducing lodging risk. In High Rainfall Zone (HRZ) production systems, where there are often high inputs of applied fertiliser and water, PGRs may be used to decrease the incidence of lodging. Though the role of PGRs to reduce lodging risk in winter wheat is well accepted, there have been inconsistent effects on yield. For example Shekoofa and Emam (2008) showed CCC increased grain yield when applied at mid tillering while Espindula *et al*. (2009) showed that CCC had no effect on yield, and TE applied at high rates reduced yield.

The aim of this research was to evaluate the individual and combined effects of two PGRs, CCC and TE, on lodging, height and yield of winter wheat over several seasons in a high input system in northern Tasmania.

Materials and Methods
Trials were located in commercial paddocks of wheat in the Hagley area in Tasmania (41°31'S, 146°54'E) over four growing seasons (2009-2012). The trials were established on commercially sown paddocks of wheat cultivars Brennan (sown 11th May 2009, 16th June 2011, 1st May 2012 at 100 kg ha $^{-1}$) and Revenue (sown 3rd June 2010 at 105 kg ha^{-1}). Weeds and pests were controlled as per commercial practice. Each trial was a randomised complete block, with four replicates. Plots were aligned perpendicular to the sowing direction and the borders sprayed out with glyphosate. Plot sizes were 1.85 m wide and 8 or 12 m in length depending on the year of the experiment. PGR treatments were applied according to Zadoks growth stage at mid tillering (GS 24) and stem elongation (GS 30). Treatments were CCC 24, CCC 30 (CCC applied at 730 g a.i. ha^{-1} at GS 24 and 30), TE 24, TE x2 24, TE 30 (TE applied at 50 and 100 g a.i. ha^{-1} at GS 24 and 30), CCC + TE 24, CCC + TE 24 & 30, CCC + TE 30 (combination of CCC and TE at 730 and 50 g a.i.

ha^{-1} at GS 24 and 30). Extra controls were added to induce lodging, GA + N (gibberellic acid at 8 g ai.i ha^{-1} and nitrogen at 15 kg a.i. ha^{1} at GS 24), early N (15 kg a.i. ha^{-1} at GS 24) and late extra N (15 kg a.i. ha^{-1} at GS 45). Plants were sampled from 0.6 m^{-2} quadrats at physiological maturity and plot harvester was used to measure yield.

Results

No lodging occurred in any treatment in any year. In 2010 no significant effects on height or yield were realised. The lack of treatment effects in 2010 may be attributed to the exceptionally wet winter with the paddock being waterlogged shortly before treatments were applied. The additional controls added to induce lodging did not differ from the nil control and hence have been omitted from results presented in Figures 1 and 2.

The effects of chlormequat and trinexapac-ethyl on plant height

PGR treatments applied at GS 30 showed height reductions in most years (Figure 1). The greatest reduction in height was achieved with CCC and TE applied at early stem elongation (GS 30). Neither the single or double TE applications applied alone at mid tillering (GS 24) reduced height.

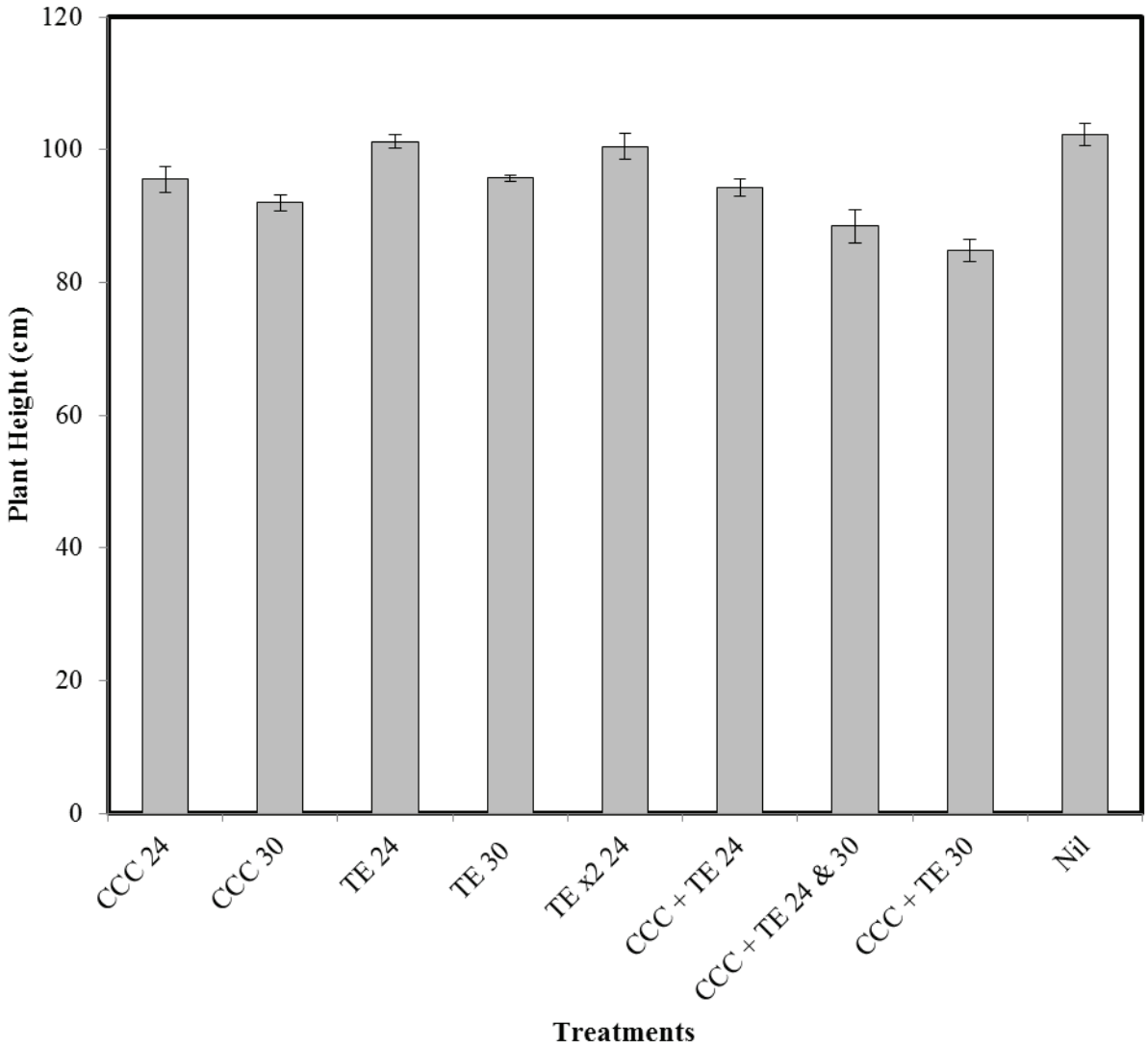

Figure 1. Effect of PGR treatments on crop height in the 2012 trial. Bars represent ± SE. PGR treatments of chlormequat (CCC) and trinexapac-ethyl (TE) applied alone or in combination were applied at mid tillering (GS 24) and/or early stem elongation (GS 30).

The effects of chlormequat and trinexapac-ethyl on grain yield

In three out of the four years there were increases in grain yield as a result of PGR application. In 2009 a single application of TE at early stem elongation increased grain yield, and this treatment was only also applied in 2012 and it tended to increase yield (Figure 2). Results indicate that generally CCC applied alone at mid tillering had the greatest increase on yield (e.g. Figure 2), though results were variable between years.

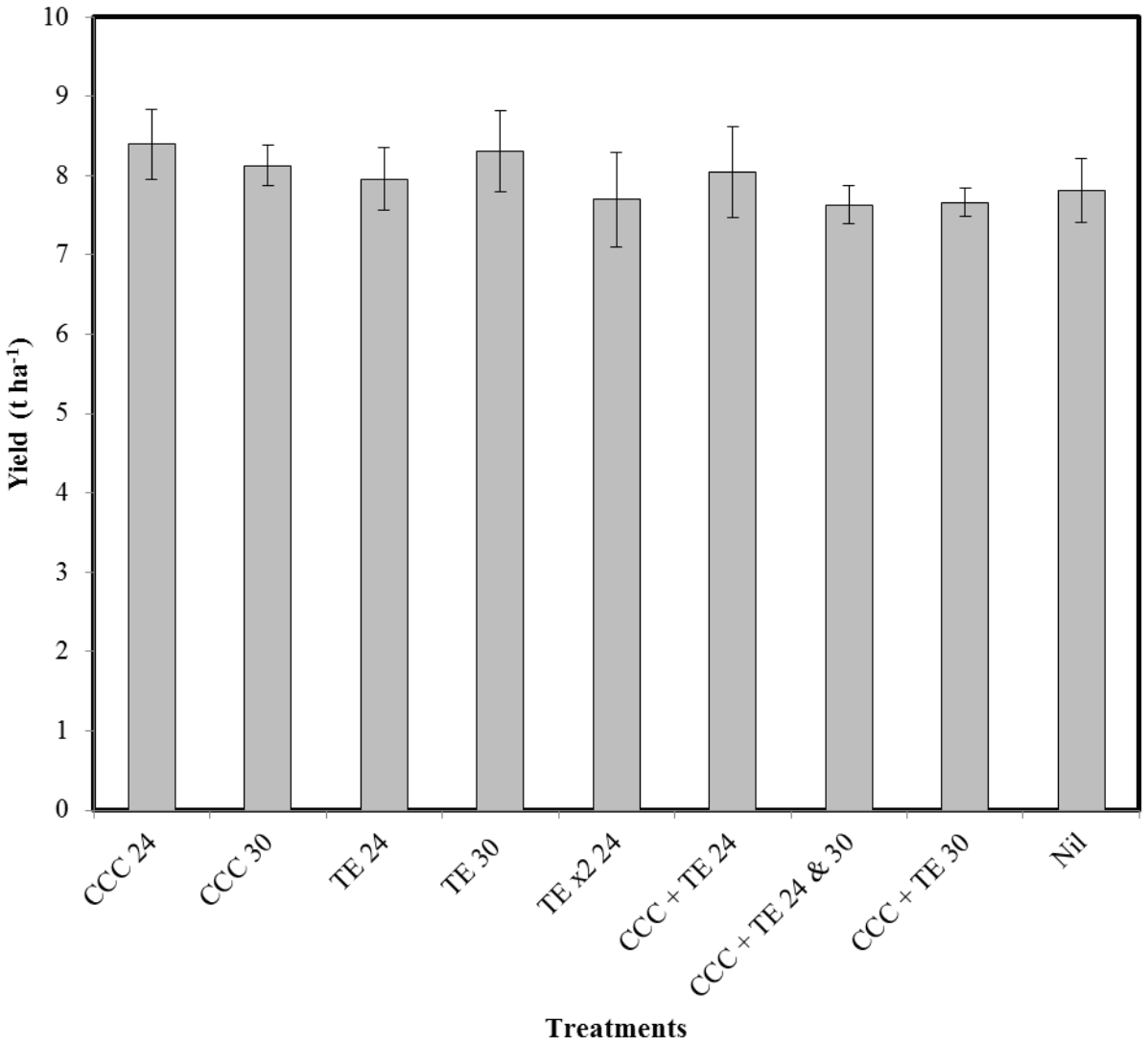

Figure 2. Effect of PGR treatments on crop yield in the 2012 trial. Bars represent ± SE. PGR treatments of chlormequat (CCC) and trinexapac-ethyl (TE) applied alone or in combination were applied at mid tillering (GS 24) and/or early stem elongation (GS 30).

Discussion and Conclusion

There was no lodging in any treatments in any year meaning PGR treatment could not be assessed to improve the stand ability of the crop. PGR treatment did however reduce height. CCC and TE applied in combination at early stem elongation (GS 30) tended to reduce plant height and hence lodging risk but in these trials did not increase yield. The double dose treatment of TE at GS 24 did not increase the height reduction as it has in other studies such as Wiersma *et al*. (2011) though these authors did suggest GS 37 as the optimum time for application of TE. CCC applied alone at mid tillering (GS 24) increased grain yield in most years, results consistent with Shekoofa and Emam (2008) and reduced plant height, though not to the extent of CCC and TE combined. TE applied at early stem elongation did reduce height (by 6% in 2012) though not to the extent of the CCC treatments, but tended increase yield. CCC applied at mid tillering and TE applied at early stem elongation decreased lodging risk through height reduction compared with the control, though not to the extent of the other treatments. They did however, tend to increase yield, so would be suggested strategy to decrease lodging risk whilst potentially having yield benefits in years when lodging risk was not high.

Acknowledgements

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Response to metsulfuron-methyl and dicamba in wheat (*Triticum aestivuum* L.) and barley (*Hordeum vulgare* L.) cultivars

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Abstract
Herbicide tolerance research has highlighted the herbicides metsulfuron-methyl (Ally®) and dicamba (Cadence®) as being particularly damaging to wheat and barley cultivars in South Australia. Response of wheat and barley cultivars to these herbicides has shown consistent yield reductions when applied at the recommended rates. Field experiment data collected from 2008, 2009 and 2010 was analysed to investigate the reoccurrence of damage by these herbicides. Grain yield results from herbicide treated plots, expressed as a % of the untreated plots, were used to determine grain yield reductions. Grain yield losses of between 3-15% were recorded in the tested wheat and barley cultivars towards metsulfuron-methyl and dicamba at the recommended rate. Cultivar sensitivity to metsulfuron-methyl and dicamba places considerable importance on ensuring testing occurs on all new breeder and current commercial cultivars to ensure growers are able to make safe application choices.

Key words
Metsulfuron-methyl, dicamba, wheat, barley, cultivar response

Introduction
In-crop herbicides have long shown a varying severity of damage across cultivars of common crop species causing problems with herbicide and cultivar selection in farming systems (Gunsolus and Curran 1991; Wicks *et al*. 1987). To evaluate the extent of this issue in South Australian (SA) crop production systems, a series of experiments were initiated in the mid 90's funded by the Grains Research and Development Corporation and the South Australian Research and Development Institute. The experiments were set up at a number of different locations around South Australia and aimed to characterise cultivar sensitivity within wheat and barley cultivars grown in the Mid North of SA over three seasons. Grain yield and normalized difference vegetation index (NDVI), as compared to the untreated control, is widely utilised as the indicator of herbicide tolerance and has shown high variation between seasons (Harrigan *et al*. 2010) suggesting that herbicide tolerance trials should be repeated across at least 2-3 seasons. It is important for these trials to take place under weed free conditions and on soils with adequate nutrition applied to remove the confounding effects of weed competition and nutrient deficiency. Seasonal variation in damage was observed in both wheat and barley to the commonly used herbicides dicamba and metsulfuron-methyl over 2-3 seasons and clearly illustrated the significant variation that both the environment and individual cultivar tolerance contributes to the outcome.

Method
Every year since the early 2000's, field experiments located near Kybunga in the Mid North of SA were conducted to assess the tolerance of a select number of breeder and commercially released wheat and barley cultivars to a range of commonly used herbicides. Cultivar selection was aimed at attaining between 2-3 seasons of data prior to wide-scale commercial use, and included 5-7 barley and 8-12 wheat cultivars. To eliminate any potential weed competition, experiments were sown relatively late in the season to allow weed germination and control prior to sowing. Commercially acceptable seeding protocols, including the use of diammonium phosphate fertilizer (DAP) with 2% zinc, knife points and press wheels resulted in a minimum till practice being achieved. Each experiment consisted of a wide range of individual herbicide treatments, in this instance dicamba and metsulfuron-methyl being sprayed at label-recommended rates to give information on varietal tolerances and safety margins, achieved through comparing grain yields. The trials were arranged as a split plot design with three replicates.

Results

Yield data obtained from 2008 to 2010 highlighted variability between dicamba (140 g ai/ha) (Cadence®) and metsulfuron-methyl (4.2 g ai/ha) (Ally®) with damage observed in different wheat cultivars. The application of each herbicide produced significantly different grain yield responses between cultivars (Table 1). Wheat cultivars Axe, Catalina, Correll and Frame were found to display tolerance to dicamba with no grain yield losses in 2008. In 2009 all cultivars displayed sensitivity to dicamba resulting in yield reductions of 3-9%. Axe and Catalina displayed repeated sensitivity in 2010 with yield reductions of 9 and 11% respectively. Axe, Catalina and Frame displayed sensitivity in 2008 trials when metsulfuron-methyl was applied, recording a 13%, 13% and 9% grain yield reduction. In 2009 Axe and Catalina displayed increased tolerance to metsulfuron-methyl while Frame recorded a 7% grain yield reduction. Axe displayed sensitivity to metsulfuron-methyl and a subsequent 15% yield reduction in 2010 while Catalina, Correll and Frame displayed no grain yield losses significantly different to the untreated control.

Table 1. The response of wheat cultivars to dicamba and metsulfuron-methyl on cultivar grain yield (t/ha as a % of the untreated control) between 2008 to 2010 at Kybunga, South Australia.

	Untreated control			Dicamba 140 g ai/ha (Z15)			Metsulfuron-methyl 4.2 g ai/ha (Z13)		
				Year					
Variety	2008	2009	2010	2008	2009	2010	2008	2009	2010
	yield t/ha			as % untreated control					
Axe	0.62	2.54	3.82	106	**91***	**91***	**87***	100	**85***
Catalina	0.72	2.58	3.94	103	**96***	**89***	**87***	101	97
Correll	0.61	2.69	4.11	105	**97***	104	96	99	98
Frame	0.65	2.29	3.69	105	**93***	99	**91***	**93***	101
Mean	0.65	2.52	3.89	105	94	96	90	98	95

* Denotes mean yields that were significantly less than the untreated control at the P<0.05 level.

Table 2. The response of barley cultivars to dicamba and metsulfuron-methyl on grain yield (t/ha as a % of the untreated control) between 2008 to 2010 at Kybunga, South Australia.

	Untreated control			Dicamba 140 g ai/ha (Z15)			Metsulfuron-methyl 4.2 g ai/ha (Z13)		
				Year					
Variety	2008	2009	2010	2008	2009	2010	2008	2009	2010
	yield t/ha			as % untreated control					
Buloke	1.71	3.38	3.95	**84***	106	102	96	**94***	103
Flagship	1.93	3.01	3.76	98	**83***	99	95	**96***	97
Hindmarsh	2.41	3.39	3.84	101	100	**90***	**91***	**96***	101
Finiss	1.73	3.08	3.56	**76***	**95***	98	97	98	98
Mean	1.95	3.21	3.78	89	96	97	95	96	99

* Denotes mean yields that were significantly less than the untreated control at the P<0.05 level.

Similarly to wheat, barley yield data highlighted the variability between cultivar sensitivity towards dicamba (140 g ai/ha) and metsulfuron-methyl (4.2 g ai/ha) (Table 2). The tested varieties Buloke, Flagship, Hindmarsh and Finiss all displayed levels of tolerance and sensitivity with seasonal variability. Buloke and Finiss displaying sensitivity to dicamba in 2008 recording 16% and 24% grain yield reductions respectively. Flagship and Finiss displayed sensitivity to dicamba in 2009 with 17% and 5% grain yield reductions. In 2010 Buloke, Flagship and Finiss displayed good levels of tolerance to dicamba while Hindmarsh displayed sensitivity respectively and incurred a 10% yield reduction. Yield reductions were observed in 2009 towards metsulfuron-methyl with Buloke, Flagship and Hindmarsh all recording 4-6% yield losses significantly different to the untreated control.

Discussion

Varietal screening of wheat and barley to metsulfuron-methyl and dicamba has previously shown varieties to suffer significant grain yield reductions when applied at label recommended rates (Ramsey *et al*. 2010). Metsulfuron-methyl and dicamba in a stand-alone application have also been observed to impact severely upon multiple wheat and barley cultivars in experiments run prior to 2012 (Ramsey *et al*. 2010). The levels of sensitivity observed to these herbicides suggested that there was a requirement for the addition of a second herbicide in a tank mix. It was observed that this was becoming a more commercially adopted practice by many growers in South Australia. Over the past 3 years there has been a change to the commonly practiced standalone application of dicamba and metsulfuron-methyl. The addition of a secondary product has suggested that this could act as a "softening" agent and in many instances help reduce the severity and frequency of the damage observed prior to 2010. The addition of the chemical MCPA (Agritone®) to tank mixes has shown to significantly reduced the incidence and severity of damage and grain yield losses, witnessed initially in the preliminary screening trials. Sensitivity within wheat and barley cultivars to metsulfuron-methyl and dicamba may suggest and be supported by long term yield data that wheat displays significantly less tolerance to both metsulfuron-methyl and dicamba than barley.

Conclusion

High degrees of variability within responses in wheat and barley cultivars to dicamba and metsulfuron-methyl during these experiments highlight the need for a holistic approach when selecting crop cultivars and herbicides to ensure financial losses do not result. Cultivar and herbicide combinations should be planned in conjunction with weed-control strategies to reduce herbicide-related yield penalties resulting from generic label recommendations for crop species. Seasonally dependent results emphasise the importance and vigilance growers need to take, depicted in historic long-term yield data. This will help growers make more informed decisions about cultivar and herbicide selection in order to minimise herbicide-related yield losses. Continued testing of newer varieties will ensure growers can confidently make management decisions to maximize profitability. This information could also be utilised by breeding programs to improve herbicide tolerance in these crops.

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Defining sowing windows for perennial tropical grasses in the low rainfall zone of Australia

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Abstract
Summer active, tropical perennial grasses have shown potential in southern Australia but establishment is risky as it requires a combination of warm but moist soils for successful pasture establishment. The aim of this study was to define optimal sowing windows for the low rainfall zone (250-400 mm) of southern Australia. By interrogating historical climatic data (SILO) using two sets of rules that identified conditions for potentially successful seed germination and pasture establishment sowing windows were identified. In general early October presents the most opportunities to successfully establish tropical grasses. However the duration of the sowing window and number of opportunities in any given year varied greatly across the region. The data is helpful for planning purposes and assessing potential suitability of different zones as field experimentation has shown that, once established, perennial tropical pastures can grow well and persist in a low rainfall environment.

Key words
Pasture establishment, perennial pastures, tropical grass, SILO, meteorological data

Introduction

Traditional mixed farming systems in the low rainfall region of southern Australia often endure a significant feed supply deficit for livestock over the summer and early autumn period that can last for up to 6 or 7 months. The reason is that the farm feed base is often focussed towards annual species in order to exploit winter rainfall. However these systems do not take advantage of occasional summer rainfall and deep soil moisture carried over from winter and spring. The use of summer-active (*i.e.* C4 of tropical origin) pasture species (e.g. *Panicum* spp., *Chloris gayana*, *Digitaria eriantha*) has been proposed as an option to reduce the summer feed deficit (e.g. Finlayson *et al.* 2012) in situations where lucerne is not a preferred or suitable option, particularly where maintaining groundcover to reduce erosion risk is a priority. Extensive areas are already established in the northern Western Australian cropping belt (Moore et al 2013). As a result, the potential for integrating perennial tropical pastures in a low rainfall crop-livestock region of South Australia and Victoria has been assessed using field experimentation at two locations, where growth and persistence (Descheemaeker *et al.* 2014) has encouraged the assessment of potential suitability of these pasture options to low rainfall areas.

Based on experience from other climate zones in Queensland (Qld), New South Wales (NSW) and Western Australia (WA), a key obstacle to more widespread adoption of summer-active perennial pastures is their difficult and risky establishment (McCormick *et al.* 2009; Moore *et al.* 2013). Especially in southern low-rainfall areas where these grasses are less well adapted than in tropical environments and relatively untried, more certain information about the optimal sowing windows for different regions and estimates of the probability of establishment success are required to better inform growers. Therefore, an exploratory study was conducted with the aim to identify the periods in the year where opportunities for sowing summer active grasses were suitable for potentially successful germination and establishment across a number of key locations in the low rainfall zone of southern Australia.

Method

The area of interest was the 250-400 mm rainfall zone of SA, NSW and Victoria. A number of locations were selected as being geographically representative of various areas within the region with farming systems potentially suited to perennial tropical grasses (Figure 1). Historical daily meteorological data from the 45-year period from 1970-2014 were extracted from the SILO climatic database as a Patched Point (Jeffrey *et al.* 2001) for selected stations at each location. An important factor in seed germination relates to the

temperature of the soil environment. However soil temperature data are not available in SILO datasets. Air temperature data are recorded 1.2 m above the soil surface and so are not reliable surrogates for conditions in the soil environment. Therefore a simple linear relationship between air and soil temperatures to 10 cm was developed based on data from a selection of 14 dryland cropping locations in the South Australian Mallee and Riverland recorded at daily intervals, usually from 2011 onwards (www.aws-samdbnrm.sa.gov.au) for the period between 21 June and 21 December. Average daily soil temperature was predicted with reasonable accuracy (R^2=0.84; $p<0.05$) with an overall median difference of -0.1 ° C (-2.0 to 3.4 ° C).

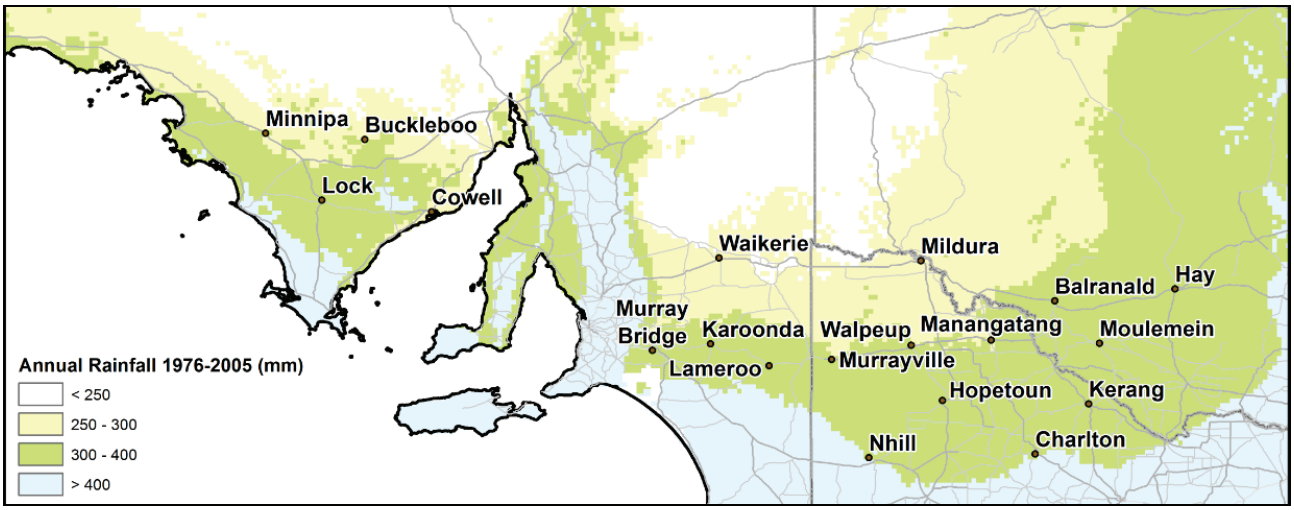

Figure 1. Location of the study sites in the low rainfall zone (250 – 400 mm) of SA, Vic and NSW assessed for their suitability for the establishment of tropical grasses.

In order to define the optimal sowing window for tropical grasses two sets of rules were developed, one aimed at determining sowing times for optimal seed germination, the second set built upon these to also consider a simplified assessment of potential for seedling survival (*viz.* establishment):
Rule Set 1 - germination suitability:

- Soil is in a warming trend: the data analysis was restricted to days between the winter and summer solstices (21 June to 22 December), soil in when the following fortnight had a higher median temperature than the one before,
- Median soil temperature: is between 15 °C and 35 °C for 5 days,
- Night time air temperature (minimum): is greater than 10 °C , and
- Sufficiently moist soils for germination: where total rainfall, divided by potential evapotranspiration (FAO56) in the 7 days preceding, is greater than 1.0

Two additional aspects expanded the germination rule set above in order to consider the potential for pasture survival beyond the seeding period to establish a pasture sward of seedlings.
Rule Set 2 - establishment:

- Frosts: when the incidence of severe frosts (-2 °C) in the next two months is low,
- Sufficiently moist soils for establishment: where the ratio of total rainfall divided by potential evapotranspiration (FAO56) in the three months proceeding is greater than 0.75

The above rules were developed based on information from various published studies from a range of laboratory, glasshouse and field experiments, extension material and experience of scientists, agronomists and farmers (e.g. Moore *et al.* 2013).

The establishment rules set required meteorological data after the planting date, whereas the germination rule set used data prior to and including the potential sowing date. In the above way, this analysis utilises the historical data as an indication of the climatic trends and conditions that might be expected in the future.

Results

The average air temperature, lagged over the previous three days, was related to the average daily soil temperature at 10 cm depth in the soil. Using the germination rules, sowing opportunities occurred on

average in 69% (82% at Murray Bridge to 60% at Lameroo and Buckleboo) of years in the study period (data not shown). All locations had at least one sowing opportunity per year (i.e. at least one day that met germination Rule Set 1). The median number of suitable sowing days per location per year was two. However when establishment was taken into account using the establishment rules, on average around 30% of years had at least one day of sowing opportunity (i.e. satisfying both the germination and establishment Rule Sets). There was a wide range across the low rainfall zone in the total number of days where sowing opportunities occurred (Table 1). The greatest number of opportunities for sowing with establishment was at Kerang and the least number was at Waikerie. The optimum period varied between locations. Of the locations shown in Figure 2, Lock (Eyre Peninsula, 371 mm average annual rainfall) showed more suitability for establishment but at Waikerie (SA Riverland, 273 mm average annual rainfall) germinated seeds would have a small chance of survival.

Table 1. Total number of days over 44 year period (1970-2014) with sowing opportunities based on rules for germination and establishment. Numbers in parentheses are the percentage of years with at least one opportunity per year.

Location	Germination days	Establishment days (%)	Location *(cont.)*	Germination days	Establishment days (%)
Kerang	201	83 (36)			
Murray Bridge	193	79 (56)	Mildura	159	34 (20)
Hay	232	75 (33)	Manangatang	154	32 (22)
Lock	177	73 (49)	Cowell	183	32 (22)
Nhill	113	57 (40)	Walpeup	123	29 (22)
Moulamein	223	52 (27)	Buckleboo	106	27 (20)
Balranald	214	52 (24)	Murrayville	122	26 (27)
Minnipa	140	50 (33)	Karoonda	133	24 (27)
Hopetoun	129	40 (33)	Charlton	273	17 (16)
Lameroo	110	39 (36)	Waikerie	155	3 (4)

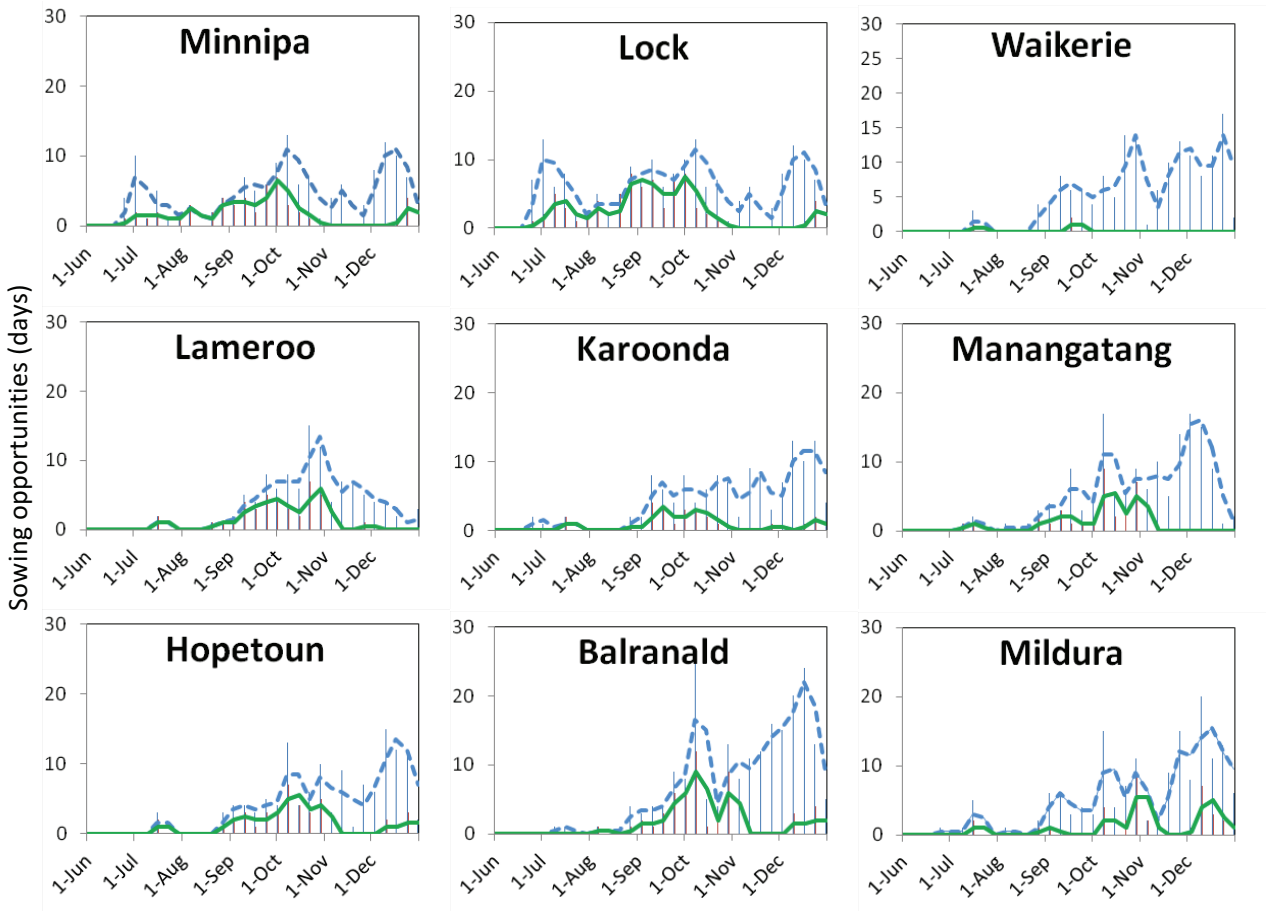

Figure 2. Subset of the locations used in the study – the y-axis represents the total number of sowing opportunities (days) for the 45 year period, divisions on the x-axis are weekly periods; the trend lines present the fortnightly moving average. The segmented lines are from germination rule set (1) and the solid lines are from the establishment rule set (2).

The time of first sowing opportunity depends on locality: on central and upper Eyre Peninsula opportunities may become available from July onwards, where as in the southern SA Mallee and Victoria opportunities start to increase from the middle of September onwards (Figure 2). Overall, early October represents the most likely time for successful germination and establishment. When is the latest farmers can sow? At many locations germination opportunities exist later than October, but by early-mid November there is very little probability of successful establishment.

Discussion

This analysis has highlighted the large variation in likely establishment opportunities for tropical species between localities in the southern low rainfall region. The study shows that opportunities for establishment will occur in most locations but there is a generally low coincidence of suitable temperatures and moisture regimes. Sowing times need to be considered in the context of conditions for germination and after sowing such as follow up rains, the severity and number of frosts, surviving summer drought etc. Use of tropical grasses by growers in Western Australia has shown that limitations to establishment can be reduced in some respects with judicious management and preparation (Moore *et al.* 2013) but in practice, in the low rainfall zone the coincidence of suitable conditions occurs over a narrow range. The limited sowing opportunities that meet the meteorological and agronomic requirements will require a highly opportunistic approach and demand monitoring and preparedness during key periods, mostly during September and October. Based on the localities studied, many growers can only expect an opportunity to establish tropical grasses one year in three

This initial data exploration has highlighted the optimum sowing windows using interrogation of climate records and a preliminary set of rules. However these may differ from the *actual* germination windows as grasses can germinate under suboptimal conditions due to hydropedesis – whereby seeds have the ability to imbibe water then dry again without loss of germinability. This is an adaption that allows the seed to remain 'primed' this also may allow the seed to be sown prior to the convergence of suitable sowing conditions.

Conclusions

Field trials in low rainfall locations in southern Australia and grower experience in low-medium rainfall regions of Western Australia have demonstrated the potential for tropical grasses to establish, persist and provide valuable summer growth and groundcover. However limited opportunities for effective establishment continue to be a major limitation to their widespread uptake. This study used an interrogation of daily climate data to highlight why establishment poses a major limitation and risk in the low rainfall zone; but has also shown that establishment opportunities can occur, particularly in localities receiving greater than 350 mm rainfall and mostly in September and October. Growers wanting to establish tropical species will need to be prepared to take a highly opportunistic approach based on well informed and judicious decisions about current edaphic and climatic conditions, as well as those forecast for the near future. Although this environment is marginal for this pasture, this information can be used to develop strategies for increased success of establishment.

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Improving the reliability of establishing legumes into grass pastures in the sub-tropics

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Abstract
Poor establishment is the most common reason for failure of pasture legumes sown into existing grass pastures on commercial farms in the sub-tropics. Although good establishment is recognised as critical to the long term productivity and persistence of legumes, most producers use low-cost and low-reliability establishment techniques such as broadcasting after either no or minimal pasture disturbance; one-pass cultivation with seed spread at the same time; or severe soil disturbance and a rough seed bed behind a blade plough. This paper reports the results of a study designed to test the impact of different fallow periods (medium – 4 months; short – 2 months; disturb at sowing and no disturbance); seedbed preparation (cultivation or zero tillage); drilling or broadcasting seed and post emergence herbicides when establishing legumes into existing grass pastures. The most common, commercially used establishment techniques of sowing legume seed into grass pastures with no disturbance or single pass cultivation treatments at sowing all resulted in establishment failure. Spraying at sowing resulted in adequate numbers of legumes. Short or medium fallows resulted in similar densities of legumes between all treatments, however treatments with greater control of the grass and post emergence weed control grew better which resulted in more seedling recruitment in the subsequent year. At 25 months after sowing only fallowed treatments with Spinnaker® post-emergence weed control achieved legume numbers above benchmark figures for establishment success. The study demonstrates that agronomic practices commonly used for grain cropping (such as fallowing to store soil moisture) can improve the reliability of establishing legumes into existing grass pastures.

Key words
Nitrogen, fixation, Caatinga stylo, desmanthus, buffel grass

Introduction

Commercially, pasture legumes have not established reliably in existing sown grass pastures in the sub-tropics (Peck *et al.*, 2011). Although good establishment is recognised as critical to the long term productivity and persistence of pasture legumes, most producers use low-cost and low-reliability establishment techniques such as broadcasting out of planes after either no or minimal pasture disturbance (e.g. fire) or one-pass cultivation where seed is sown at the same time or severe soil disturbance and a rough seedbed behind a blade plough used for controlling woody regrowth (Peck *et al.*, 2011). In the black spear grass zone of central and southern Queensland, surface sowing legumes has been shown to be unreliable with an 80% failure rate (Cook *et al.*, 1992); it is likely that sowing into competitive sown grass pastures like buffel grass in lower rainfall areas has even higher failure rates. This paper reports early results of an establishment study near Wandoan in southern inland Queensland.

Methods

The study site was established on a brigalow grey cracking clay, dominated by existing buffel grass (*Penessetum ciliare*) and included two replicates of 16 treatments. The study plots were 5.5m x 20m, with 4.5m of grass left between each plot. Fourteen of the treatments were of split plot design, where half of the plot (10m x 5.5m) was drilled using a single disc opener planter while the other half was broadcast onto the soil surface; the one-pass cultivation treatments described below did not have split plots as graziers would most likely spread seed at the same time as cultivation as opposed to drilling seed as part of a second operation. The study was planted on the 13th of February, 2013. Progardes variety desmanthus (*Desmanthus spp.*) seed was applied at 6kg seed/ha. Treatments were a combination of fallow period, seedbed preparation (zero tillage or cultivated) and post-emergent weed control. A summary of treatments applied in the study is presented in table 1. In this study, fallow was defined as the killing of grass to reduce competition and store

soil water (buffel grass is however a perennial grass with high seed production, therefore single treatments or short fallows rarely kill all tillers in all plants or the soil seed bank).

Table 1: Summary of study treatments applied

Fallow period	Fallow treatment	Post plant weed control
No disturbance	Slash at sowing	Nil
	None	Nil
Disturb at sowing	Deep rip	Nil
	Spray (glyphosate)	Nil
	Cultivate (tynes)	Nil
Short (2 months)	Spray (zero till)	Post-emergence herbicide as required
		Nil
	Cultivate	Spinnaker*® (active: 700 g/kg imazethapyr)
		Nil
	Spray + cultivate	Nil
Medium (4 months)	Spray (zero till)	Post-emergence herbicide as required
		Nil
	Spray + grass seed	Nil
	Cultivate	Spinnaker*® (active: 700 g/kg imazethapyr)
		Nil
	Cultivate + grass seed	Nil

At 5 and 9 weeks; and 9, 15, 23 and 25 months after germinating rains, legume numbers, height and dry matter (DM) production were recorded. At 15 months and 25 months legume numbers and dry matter production of both grass and legume were recorded. The trial site was grazed during winter after pasture measurements were taken in autumn.

Results

The site had a very dry spring and early summer leading up to sowing which resulted in relatively low amounts of stored soil moisture in fallowed treatments and reduced in-fallow spray efficacy. Very good germinating rains were recorded and rainfall was close to average in the nine weeks after planting. The good early season was followed by a very dry spring and early summer.

The undisturbed grass, slashed grass, cultivated at sowing (tynes) and deep rip treatments all resulted in low numbers of legumes (Figure 2), with very poor growth (Figure 1). Sprayed or cultivated fallows resulted in higher legume numbers with better growth than low disturbance treatments. Legume growth at 15 months after sowing is shown in figure 1. No significant difference was measured between sowing methods (drilling and broadcast).

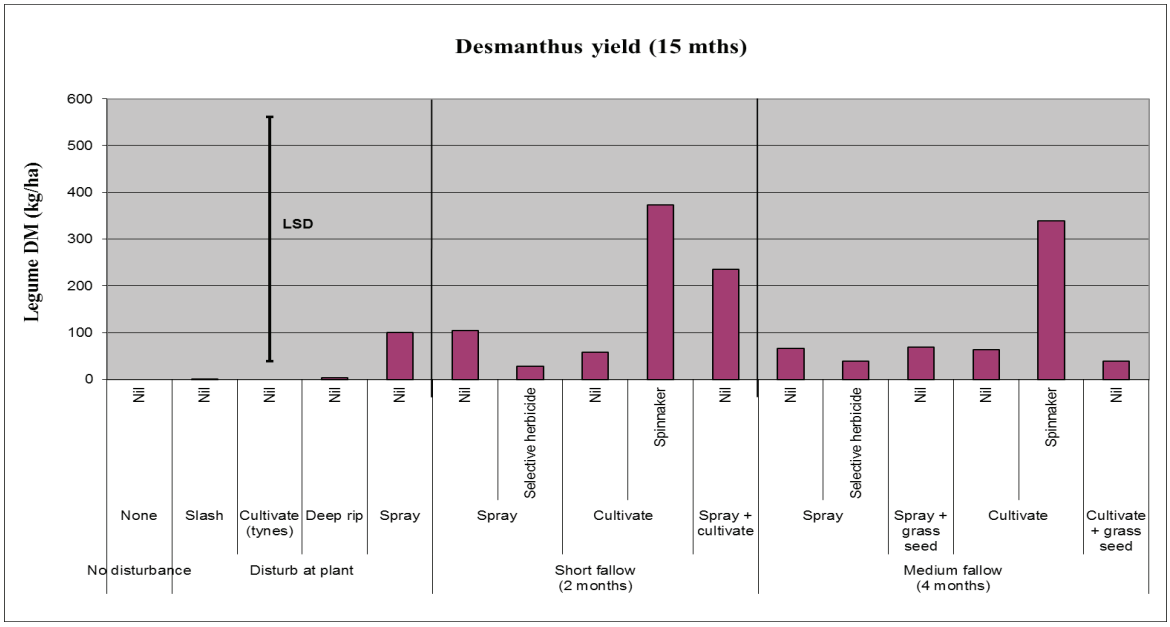

Figure 1: Legume dry matter production (kg/ha) at 15 months after sowing. No significant difference was measured between sowing methods (drilling and broadcast) and for this reason, results are presented as combined drill and broadcast averages for each treatment. Undisturbed grass, slashed grass, cultivated at sowing (tynes) and deep rip treatments failed to produce statistically meaningful biomass. No significant difference was measured between any of the other treatments.

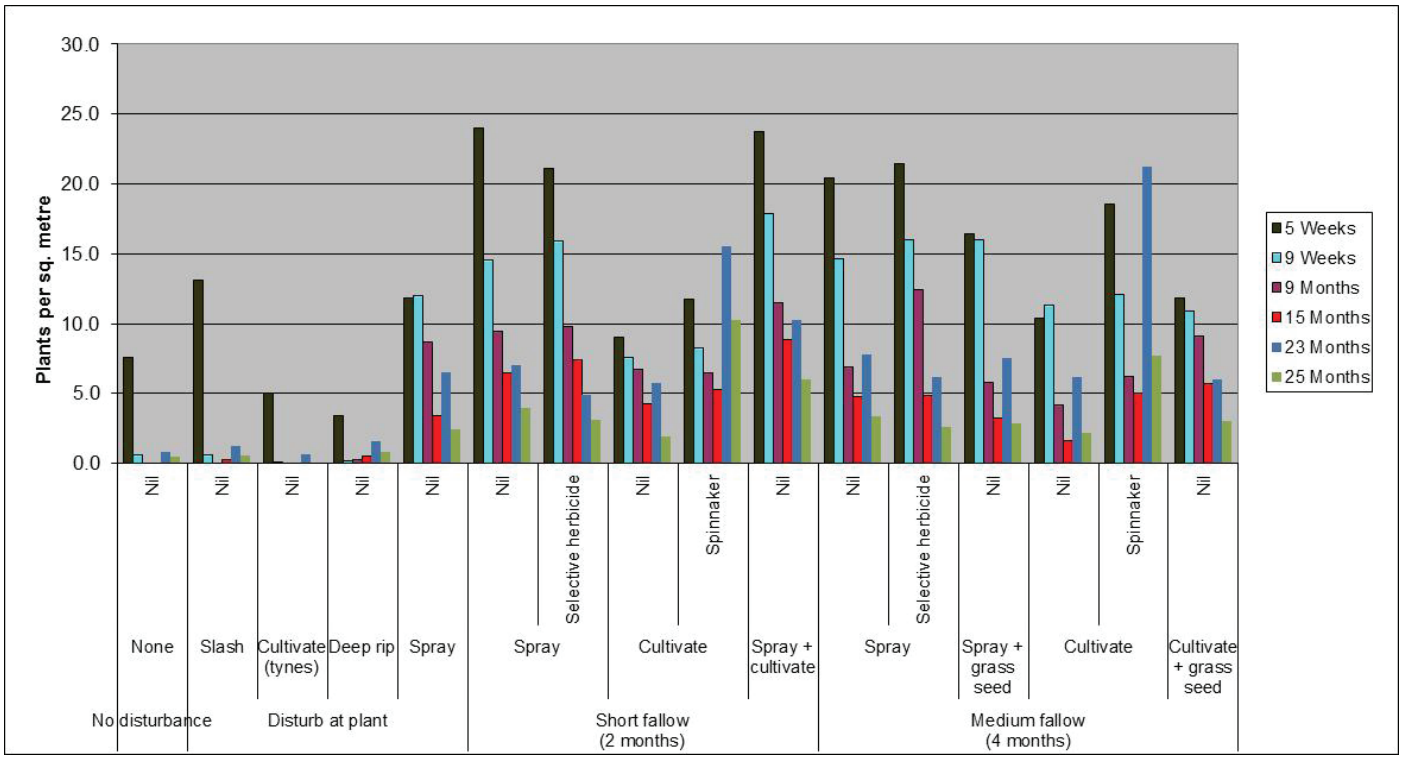

Figure 2: Legume numbers per square metre (*Desmanthus spp.*) at six recording periods after sowing for the different treatments. Treatments were a combination of fallow period (medium, short, disturb at sowing or no disturbance of the grass pasture); seedbed preparation of cultivated fallow or zero tillage fallow (labelled spray) or a combination of both; and post-emergence weed control by using Spinnaker® on cultivated plots or a combination of herbicides for zero tilled treatments.

Discussion

For the purposes of this study, the benchmark target for legume density for the species was greater than 4 legumes per square metre. Referring to this benchmark, the establishment techniques most commonly used by industry of either no disturbance of the existing grass pasture or one-pass cultivation treatments all resulted in establishment failure (<1 legume/m^2) (Figure 2). At 15 months after planting, all fallowed treatments and the spray at sowing treatments were close to this benchmark. By 25 months however, most treatments had recorded strong declines in legume numbers with increasing time since sowing, with the exception of the Spinnaker® and spray plus cultivate treatments, which declined less than other treatments, and exceeded the benchmark at 25 months (Figure 2).

Legume biomass data for 15 months post-sowing was analysed using ANOVA. The undisturbed grass, slashed grass, cultivated at sowing (tynes) and deep rip treatments produced statistically insignificant biomass and were thus deemed failures. No significant difference was detected between any of the treatments that did record legume biomass at 15 months (Figure 1). Raw data totals showed Spinnaker® treatments and the spray plus cultivated short fallow treatment recorded the greatest DM, while other short and medium fallows were intermediate. While not statistically different from other treatments that produced legumes at 15 months, the recorded greater legume productivity of the Spinnaker® and spray plus cultivate treatments is presumably due to a greater reduction in grass competition. It seems apparent that this greater legume productivity gave rise to these treatments having greater recruitment (23 month recording) and increased legume number by 25 months (Figure 2). These treatments were the only ones to end up with >5 legumes/m^2. Given that nitrogen fixation and animal production are directly related to legume production, these three treatments with greater DM production were considered successful at 25 months. The establishment techniques that resulted in more moderate legume numbers and DM production may still ultimately be successful, but they will take longer to reach their production potential.

At 23 months all treatments recorded increases in total legume numbers (Figure 2). For the treatments with very poor legume growth in the previous year (i.e. no disturbance, slash and cultivate at sowing treatments) this increase in legume numbers would largely be on account of a softening of originally sown hard seed as

legume were small with low numbers and therefore very little seed would have been set. For other treatments that grew greater amounts of legume, the increase in legume numbers was likely to have been a combination of both seed softening and seed set by legumes established in the previous summer growing season. The much greater recruitment within the Spinnaker® treatments reflects reduced grass competition and greater legume DM, though this is not statistically verifiable. This greater productivity led to these being the only treatments to meaningfully increase legume numbers from the 15 month to the 25 month measurements. The spray at sowing treatment produced much greater legume numbers and DM production than the cultivate at sowing treatments. The spray treatment produced a particularly good kill of the grass pasture as it was timed when the grass was very leafy and actively growing. There was very good germinating rain and follow up rain within a fortnight after planting which also contributed to the success of this treatment. In other years this treatment is likely to have been less successful if the initial kill and good follow up rain had not occurred. In subsequent trials the spray at sowing treatment has resulted in low legume numbers in the first season after sowing due to a lack of effective grass kill and variability of follow up rain.

Conclusions

Poor establishment is the most common reason for failure of pasture legumes in existing commercial grass pastures. Fallowing to store soil moisture and control competition from the existing grass pasture improved establishment. Greater control of competition through the use of post-emergence herbicides like Spinnaker® increased establishment success. Industry needs to adopt longer fallow management when establishing legumes into existing grass pastures for them to realise their potential to improve productivity and economic returns in the sub-tropics.

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Factors affecting the adoption of subtropical grasses in the Northern Agricultural region of WA

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Abstract
Perennial grass-based pastures grown on pale deep sands in the Northern Agricultural Region of WA have reduced erosion and provided out of season production. Over the past decade, about 50,000 ha of subtropical perennial pastures (mainly Gatton panic and Rhodes grass) have been sown in areas receiving at least 350 mm average annual rainfall. However, this is well below the 850,000 ha of suitable soils. This paper investigates the drivers and barriers to the adoption of perennial grasses and associated technologies: pasture cropping and companion legumes. Survey questions were developed for three target groups: farmers with no perennial grasses, farmers with some perennials (<200 ha), and farmers with large areas of their farm (>15% or >200 ha) under perennial grasses. Forty seven farm businesses completed the survey which was distributed at workshops or responded to an online survey. An interest in livestock was an important driver for adoption of perennial grasses. For the eight growers without perennial grasses the major constraint was the cost of establishment followed by the risk of establishment failure with the financial benefits not being clear. For the 39 farmers who had perennials the major reasons they adopted perennials was increased out-of-season feed, increased production, reduced erosion risk and increased profitability. For the 15 farmers that had large areas under perennials, the major weakness of their perennial based system was lack of or low companion legumes followed by difficulties with grazing management especially in dry seasons. The survey is complemented by two case studies, one farmer who has adopted subtropical grasses and one who has not.

Key words
EverCrop, pasture cropping, companion legume, practice change

Introduction
In the Northern Agricultural Region (NAR, which extends ~500 km north of Perth and ~100 km inland) an estimated 20% of the 2.0 million hectares of agricultural land are pale deep sands which have low fertility and low water holding capacity. Due to the low productivity of annual pastures on these soils and the high risk of wind erosion, farmers and researchers have evaluated alternative pasture species on these soils since the 1980s (Moore 2014). The fodder shrub tagasaste (*Chamaecytisus palmensis*) was successful on these poor sandy soils but it has some management limitations. Introduced subtropical perennial grasses have been tried in the area but with mixed success. As the technology improved particularly in relation to the establishment on non-wetting soils the area sown to subtropical grasses grew substantially and since 2000 more than 50,000 ha have been sown in the NAR. Adoption has been driven by increased pasture production in autumn–early winter, provision of out-of-season green feed, and their ability to reduce the risks of wind and water erosion by maintaining groundcover throughout the year (Moore 2014). The main subtropical species have been panic grass (*Megathyrsus maximus*) and Rhodes grass (*Chloris gayana*).

Pasture cropping over subtropical grasses is a more recent innovation in the NAR (Lawes 2014). Farmer interest was sparked initially by the NSW experience (Miller 2009) as it could provide additional income. Growth of summer active (C4) perennial pasture occurs in late spring and summer while winter annual crops grow over winter and early spring. Pasture cropping systems exploit this dynamic providing both grain and livestock income. Although perennial-based farming systems are continuing to increase in size there is a large gap between actual and potential adoption. This study as part of EverCrop and a Caring for our Country project examined the factors influencing the adoption of subtropical perennials and pasture cropping.

Method
Social science survey
The structure of the survey and questions were developed in a workshop with key stakeholders (consultants, local farming groups and the Department of Agriculture and Food, WA extension specialists). From the workshop 3 target groups were determined; farmers with no perennial grasses, farmers with some perennial

grasses (<15% of the farm or <200 ha) and farmers with large areas of perennial grasses (>15% of the farm or >200 ha). For each target group there were four to five sets of questions. One set had a list of responses for which the respondents could either rate as not applicable, or as low, moderate or high importance. For some questions the respondents were asked to select the three main reasons, constraints or weaknesses. For some questions the respondents were asked to give a rating from 1 to 5 in terms of either agreeing or disagreeing with a series of statements relating to the establishment and management of perennial grasses and related technologies like companion legumes and pasture cropping. The respondents completed the survey over the period from February to April 2012 either online using 'Survey Monkey' or a hard-copy at workshops which was subsequently entered into Survey Monkey. Some questions were similar between the group with some perennials and the group with large areas of perennials so the results were combined.

Case Studies
Two case studies are described which highlight differences in how farmers perceive and use perennial grasses. The information was collected between 2011 and 2014 from semi-structured interviews and informal discussion between at least one of the authors and the farmers involved.

Results
Social science survey
Forty seven farm businesses completed the survey. There were eight respondents who had no perennial grasses and on average their farms were larger (2725 ha, 52% crop) than the 24 respondents with some perennial grasses (1765 ha, 46% crop). There were 15 respondents who had larger areas of perennials and on average they had less crop area (17%) than the other two groups.

Farmers without perennial grasses. For the eight farmers with no perennial grasses the major constraint to adoption was the cost of establishment (7 rated this of high importance, 1 rated it as moderate), while second order constraints were risk of establishment failure (3 rated as high importance, 2 rated it as moderate) and that the financial benefits were unclear (3 rated as high importance, 3 rated it as moderate). A higher return from livestock was the most important factor (5 responses when asked to select the top 3 reasons) that would motivate them to trial perennial grasses, while more information on productivity (4 responses) and availability of incentive schemes (3 responses) were second order factors. Over half of the respondents believe that perennial grasses had a role on their farm in the future (rating of 4 or 5 with 1 = strongly disagree to this statement and 5 = strongly agree). All of the farmers were aware to some degree of pasture cropping (average rating of 4.0). However, they were neutral in terms as to whether it had a role on their farm (average rating 3.3).

Farmers with perennial grasses. For the 39 farmers who have perennial grasses there were a range of reasons for growing them or advantages to growing them with generally small differences in importance (rating 1 to 3, with 1 = low importance and 3 = high importance):
- increased production and reduced erosion on poor sandy soils (average rating 2.5, 64% rated it as high importance)
- increased out of season feed (average rating 2.3, 51% rated it as high importance)
- increased profitability (average rating 2.3, 51% rated it as high importance)
- improved soil health (average rating 1.9, 31% rated it as high importance)
- flexibility with pasture cropping (average rating 1.1, no one rated it as high importance, 5 indicated it was not applicable)

Nineteen of the 24 farmers that had some perennial grasses were planning to expand the area within 2-3 years. Of the 5 that were not expanding the area the major reasons were: out-of-season production is variable, risk of establishment failure and sub-optimal perennial plant density (poor persistence) (3 responses for each, when asked to pick the top three). Of lower importance (2 responses) were no suitable soils, cost of establishment and previous poor establishment.

The 15 farmers with large areas of perennial grasses identified the major weakness as lack of or low companion legumes (8 responses), while second order weaknesses were management in dry seasons (5 responses), grazing management (5 responses) and persistence (4 responses). Lower order weaknesses were; financial benefits are unclear, insufficient productivity of perennial grass-based pastures and risk of livestock disorders (all with 3 responses). There were 4 farmers who said that they had no major weaknesses with their perennial grass-based pastures.

For those farmers with large areas of perennial grasses to maximise the profitability of their perennial grass-based feed base the major needs were: more information on fertiliser requirements (8 responses) and more information on companion legumes (7 responses). Second order needs were a reliable package for summer sowing legumes (4 responses - Summer sowing is a technique to introduce hard seeded French serradella cultivars into pastures), more information on grazing systems and more information on reducing livestock disorders (both 3 responses). There were five farmers who said there were no major constraints.

In terms of pasture cropping the 39 farmers who have perennial grasses were more likely to disagree with statements that they have the information to pasture cropping (average rating of 2.5 with 1 = strongly disagreeing and 5 = strongly agreeing), the skills and experience to adopt pasture cropping (average rating 2.5) and plan to adopt within two years (average rating 2.6). They were neutral on the statements that pasture cropping has a role on their farm (average rating 3.1) and they have the confidence to adopt (average rating 2.8). In terms of annual legume content in their perennial pastures the farmers who more likely to disagree that they have a good content (average rating 2.5) and more likely to agree that they need to increase the content (average rating 3.9). They were also more likely to agree that they were aware of the summer sowing of annual legumes (average rating 3.2) and they need more information on the technique (average rating 3.4).

The main sources of information for perennial grasses and related technologies were field walks and field days (selected by 87% of the 39 respondents), while other important sources of information were other farmers (79%) and experienced growers (72%). Second order (36-51%) sources of information were a farming group (Evergreen Farming), the Department of Agriculture and Food, local natural resource management groups and the rural press.

Case studies

Farmer A is located near Geraldton and has 1200 arable hectares. The average annual rainfall is 465 mm of which 16% occurs outside the growing season. Cropping is a minor component of the enterprise. There are 900 ha of perennial grass based pastures, panic grasses are the dominant species sown with smaller amounts of Rhodes grass, kikuyu (for deep white sands) and Giant couch. The soil type consists of deep sand and sand over gravel with quality varying from poor sands to good yellow sand. On average the farm carries 800 head of cattle consisting of a mixture of 200 breeders their calves plus trade cattle. They buy in cattle around June and sell as many as they can between Christmas and February including their own calves. This cycle matches the availability of pasture on the property.

The main reason they are growing perennials is because they are livestock producers, the bulk of the property is not suited to cropping and the shallower soils don't seem to be suited to annual species.
Perennial pastures have increased the carrying capacity. Farmer A believes that the carrying capacity has doubled and now considers rain at any time of the year as valuable. Since establishing the perennial pastures summer rain has been infrequent. The perennial grasses have also improved the ground cover reducing the risk of wind erosion.

Farmer A has been pasture cropping since 2009. They were interested initially in pasture cropping as a way to spell the perennial pastures because under a crop they are not grazed for 6 months. Subsequently they saw a place for it in second year stands of perennial pastures. This is because when establishing perennial grasses in late winter-early spring the annual pasture are sprayed out, so there is no seed-set in the year of establishment. Therefore crop adds to the density and if it is a cereal and depending on the season they can either graze or harvest the grain. Barley and lupin have been tried and yields have been sufficient to justify the expense of cropping.

Farmer B is located near Moora and farms 1450 arable hectares with 500 mm average annual rainfall of which 20% occurs outside the growing season. Average cropping area is 55% and livestock enterprise involves buying and selling sheep. They buy sheep in spring when the prices are lower and run them over summer on the stubbles and they are generally sold before the break of season. The dominant soil type on the property is yellow sandplain (75%) and 25% gravelly soils, with 140 ha of tagasaste on infertile deep sands. The rest of the non-crop area is volunteer annual pastures.

Tagasaste is used for sheep grazing, to control salinity/waterlogging, to provide flexibility in responding to variable seasonal conditions including out-of-season rainfall and to reduce wind erosion. Farmer B does not intend to grow perennial grasses and said that reduced trafficability was a key factor. A second issue is the risk of establishment failure and wind erosion at establishment. In addition crop yields are increasing on the soil they were considering for growing perennial grasses, because of the adoption of new technologies such as spading. This has overcome water repellence by bringing up subsoil clay. Also subterranean clover suits their system. It can be grazed heavily and it sets seed, it handles herbicides and it always comes back after cropping. If there was no issue with trafficability and they were slightly more committed in terms of livestock then they would consider perennial grasses.

Farmer B hosted a long-term pasture cropping trial and therefore observed the results first hand (Lawes 2014). The farmer's thoughts on pasture cropping were that you get both crop and pasture with the opportunity of the pasture to respond to out-of-season rain. The trial found that overall the productivity is increased (crop and pasture) which he finds promising in this climate. The trial showed no yield loss but his thoughts were that if you went north then the situation changes and trials are showing there is a yield loss. The farmer's belief is that if there is a hint of yield loss many farmers would not adopt the technology. For Farmer B even though there was increased productivity he would not consider pasture cropping because good yields are achieved without perennial grasses especially with techniques like spading to reduce water repellence and if you had perennial grasses there may be issues with trafficability. Farmer B believes that pasture cropping will not be widely adopted.

Discussion and conclusions

The survey of farmers with large areas of perennials (>15% of the farm or >200 ha) and the example of Farmer A show that perennial grasses give a clear relative advantage to their livestock system. The major reasons for adoption of perennials by these farmers are that livestock is their main focus, they have higher percentage of low quality soils which are less suited to cropping and perennial grasses are more productive and they reduce wind erosion compared to annual pastures.

For those farmers who have a greater percentage of crops, less livestock and a lower proportion of poor quality soils the relative advantage of growing perennials is lower. Farmer B is one example of this group with tagasaste replacing the need for perennial grasses. For these farmers the disadvantages like cost of establishment and risk of establishment failure are more prominent, the advantages are not as clear and possibly there is less motivation to make the system work. Adoption or expansion (or dis-adoption) of perennial grass-based farming systems will depend on how much focus the farmer have on livestock, the area of lower quality soils on their farm, the degree of productivity increase by the perennials, the amount of out-of-season rain, the cost-benefits of other technologies (such as spading) and the relative profitability of livestock compared to crop. Those farmers who have no perennial grasses probably have an even greater focus on crop and may try alternative technologies to improve the productivity of their soils rather than growing perennial grasses.

Pasture cropping is generally viewed favourably by those who have perennial grasses. However, most farmers do not see the technology as a reason for adopting perennial grasses rather it adds to the advantages of growing perennials. Perennial systems are a way to reduce the risk associated with farming in this environment (Robertson 2014) and are valued by mixed crop-livestock farmers who responded to the survey. Additional research and development is required to continue to improve the profitability of perennials in cropping systems. Technologies like pasture cropping and increasing the legume content using summer sowing are examples of such research.

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Medics in southern Queensland: effects of sowing method, weed control and phosphorus application on plant population and biomass

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Abstract
Declining sown pasture productivity as a result of a tie-up in plant available soil nitrogen is an ongoing constraint to grazing production across the brigalow bioregion of central and southern Queensland. Research suggests that legume establishment offers the most cost effective long-term remediation strategy for improving pasture quality and yield. Within southern Queensland, medics (*Medicago* spp.) can provide valuable winter contributions to dietary protein and soil nitrogen, however establishment and yields are frequently poor and soil phosphorus often limiting. An experiment was established across two soil types (brigalow clay and poplar box red loam) 70 km north of Goondiwindi, Queensland to investigate the effects of sowing method, weed control and phosphorus fertiliser application on the establishment and yield of a mix of three medic cultivars (*Medicago truncatula cv. Jester & cv .Caliph and Medicago orbicularis cv. Bindaroo Gold*). On both soil types, plant population and biomass were significantly improved via direct drilling of seed as compared to broadcasting. On the loam, drilling increased average populations by between 519 and 1,900% above those recorded in broadcast treatments and improved biomass by between 144 and 315%. On the clay soil, drilling increased populations by between 339 and 983% above those measured in broadcast treatments. Clay soil drilling showed biomass improvements of between 124 and 1,368%. No significant biomass or legume population treatment effects were observed on the clay soil. No significant treatment effects were observed for yield on the loam soil. This study implies that medic establishment, plant populations and biomass can be greatly improved through the application of seed drilling.

Key words
Agronomy, grazing, buffel grass, yield, zero-till, fallow

Introduction
Declining sown pasture productivity as a result of a tie-up in plant available soil nitrogen is an ongoing constraint to grazing production across the brigalow bioregion of central and southern Queensland (Peck et al., 2011). Research suggests that legume establishment offers the most cost effective long-term remediation strategy for improving pasture quality and yield (Peck *et al.*, 2011). Within southern Queensland, medics can provide valuable winter contributions to dietary protein and soil nitrogen; however, establishment and yields are frequently poor and soil phosphorus often limiting (Peck *et al*., 2011).

An experiment was established across two vegetation - soil associations (brigalow clay and poplar box red loam) to investigate the effects of weed control, sowing method (drill v broadcast), and phosphorus fertiliser application on the establishment and yield of a mix of three medic cultivars (*Medicago truncatula cv. Jester & cv. Caliph and Medicago orbicularis cv. Bindaroo Gold*).

Methods
Two experimental sites were selected on a mixed farming enterprise 70 km north of Goondiwindi, Queensland. One site was a brigalow clay soil, while the other was a poplar box red loam. Both sites were dominated by buffel grass (*Pennisetum ciliare*). The sites consisted of four replicated treatment plots, each 20m x 5m in size.

Both sites were fallowed for a period of six months via either zero-till herbicide application or cultivation. The seedbed fallow preparations can be summarised as follows:

- Zero-till with post-emergent selective herbicide.
- Cultivation with Spinnaker® 700 post-emergent herbicide.
- Cultivation with phosphorus applied at 20kg/ha.
- Cultivation with phosphorus applied at 20kg/ha and Spinnaker® 700 post-emergent herbicide.

Zero-till herbicide applications were conducted using a mix of Roundup® at 2L/ha and LI-700® wetting agent at 250ml/ha. Post-emergent selective herbicide plots were treated as required with either Basagran® at 1L/ha with LI-700® at 200ml/100L or Verdict 520® at 100mls/ha with LI-700® at 200ml/100L. In the cultivation treatments that received post-emergent herbicide, Spinnaker® was applied at a rate of 50g/ha. Chemical active constituents are summarised for all applied herbicides in Appendix 1.

Each plot was divided in half and each half randomly assigned to be planted via either broadcast or drilling means, in late April 2014. An equally weighted mix of three medic cultivars (*Medicago truncatula cv. Jester & cv.Caliph and Medicago orbicularis cv. Bindaroo Gold*) was sown at a total seeding rate 3kg/ha. Drilling was conducted using a single disc planter with seeds planted to a shallow depth (<10mm). Broadcasting was done by hand. Phosphorus was applied at the time of planting at a rate of 20kg/ha in the form of superphosphate via shallow tines to the relevant plots. Rigid mesh grazing exclosures (2m x 1m) were erected in in the centre of each half of each plot (one in the broadcast end and one in the drilled end). Plots were measured within the grazing exclosures for plant population and total medic dry matter using 1m x 1m quadrats at the end of September 2014.

Results and Discussion

Plant population and biomass data for both soil types is presented in figures 1 and 2. Table 1 summarises treatments for which significant differences in plant population and biomass were measured. As previous work and industry observation have shown yields and populations were higher on the clay soil than on the loam (Table 1, Figure 1 and Figure 2) (Lawrence and French, 1992 , Peck *et al*., 2011). On both soil types, total plant population and biomass were significantly improved with direct drilling of seed as compared to broadcasting (Table 1, Figure 1 and Figure 2). On the loam, drilling increased average populations by between 519 and 1,900% above those recorded in broadcast treatments and improved biomass by between 144 and 315%. On the clay soil, drilling increased populations by between 339 and 983% above those measured in broadcast treatments. Clay soil drilling showed biomass improvements of between 124 and 1,368%. Loam soil broadcasted legume populations were significantly higher on cultivated seedbeds as compared to zero-till seedbeds. Cultivation, in combination with Spinnaker® post-emergent weed control produced significantly higher legume populations than all other loam soil treatments. No significant biomass or legume population treatment effects were observed on the clay soil. No significant treatment effects were observed for yield on the loam soil.

Observation of graphically presented mean data for yield and biomass (Figure 1 and Figure 2) appears to hint at other possible interactions which may warrant further investigation. For instance on the loam, phosphorus application appears to benefit biomass production. On the clay soil, Spinnaker® may have had an antagonistic effect on legume biomass and population. Neither of these observations are statistically verifiable with the existing data set, however given the limited degrees of freedom within the statistical analysis (3 for treatment and 4 for sowing method), future experiments could be better designed to investigate these factors further.

Table 1: Summarised mean legume numbers (plants/m2) and biomass (kg/ha) for clay and loam soil types. Treatments demonstrating significant difference are nominated.

Treatment	Sowing method	Loam Mean Plants/m2	Mean Biomass (kg/ha)	Clay Mean Plants/m2	Mean Biomass (kg/ha)
Zero-till, post-em. Herbicide	Broadcast	0.7a			
Cult, Spinnaker®	Broadcast	4.3ab	231	7.8	260
Cult, P	Broadcast	5.3ab			
Cult, P, Spinnaker®	Broadcast	4.0ab			
Zero-till, post-em. Herbicide	Drill	13.3b			
Cult, Spinnaker®	Drill	46.3d	704.5	47.3	915
Cult, P	Drill	33.0c			
Cult, P, Spinnaker®	Drill	27.0c			
	LSD:	9.94	503.35	12.46	516.65
	P value:	0.015	0.021	<0.001	0.016

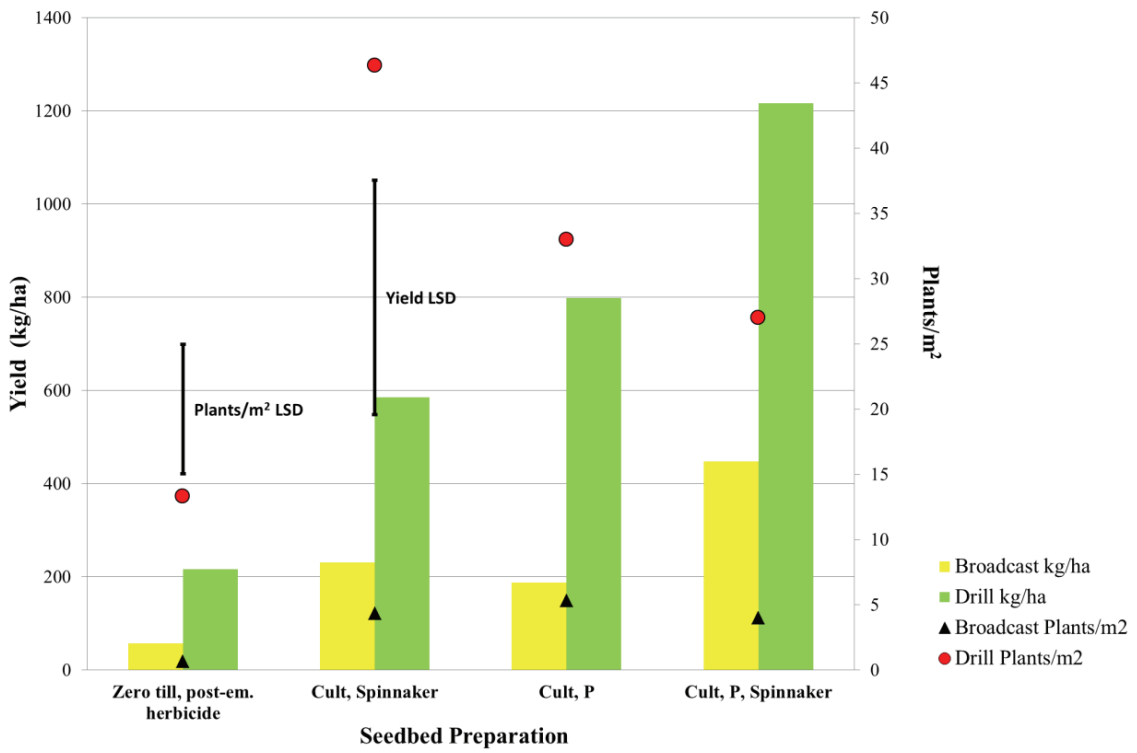

Figure 1: Average total medic dry matter yield (kg/ha) and plant population (plants/m²) responses to varying seedbed treatments at the loam site.

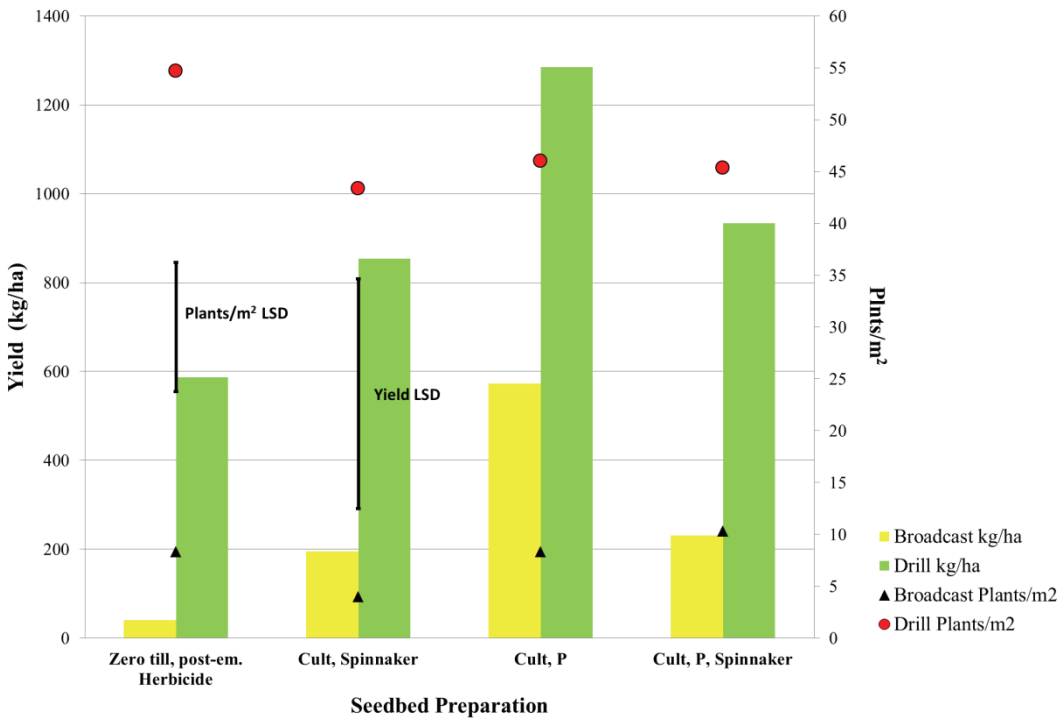

Figure 2: Average total medic dry matter yield (kg/ha) and plant population (plants/m²) responses to varying seedbed treatments at the clay site.

Conclusions

Medic dry matter yields and populations were higher on the clay soils as expected. On both soil types, medic population and biomass were strongly improved with direct drilling of seed as opposed to broadcasting. Although not statically verifiable, medic responses to phosphorus on the loam soil may warrant further investigation. Spinnaker® application may produce antagonistic effects on legume biomass production on heavier clay soils and this may also hold merit as a topic of future investigation.

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Appendix

Appendix 1: Active constituents of herbicide chemicals applied in the study.

Chemical Trade Name	Active Constituent
Roundup®	540 g/L glyphosate (present as the potassium salt)
LI-700®	350g/L soyal phospholipids, 350g/L Proprionic acid
Basagran®	480 g/L bentazone (present as sodium salt)
Verdict 520®	520 g/L haloxyfop present as the haloxyfop-R methyl ester
Spinnaker®	700 g/kg imazethapyr

Evaluation of temperate legumes for use in tropical perennial grass pastures in central western NSW

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Abstract
Central western NSW is characterised by aseasonal, low (<500 mm MAR) and highly variable rainfall resulting in gaps in feed-based production. In a MLA funded project we aim to provide flexibility to livestock enterprises with improved pastures that incorporate temperate and tropical legumes into tropical perennial grass (TPG) pastures. In June 2013, 16 temperate legumes and two non-legume treatments were sown into replicated plots at Trangie. Herbage mass was assessed at approximately 6 week intervals between mid May and late October 2014. Two attempts to establish digit grass (*Digitaria eriantha*) cv. Premier into the plots failed. The highest herbage mass values were recorded for barrel medic (*Medicago truncatula*) cv. Caliph (1,952 kg DM/ha) and cv. Jester (1,632 kg DM/ha), and woolly pod vetch (*Vicia villosa*) cv. Haymaker (1,058 kg DM /ha). The lowest herbage mass was recorded for French serradella (*Ornithopus sativus*) cv. Margurita, Persian clover (*Trifolium resupinatum*) cv. Nitro Plus and purple clover (*T. purpureum*) cv. Electra (<200 kg DM/ha). Here, a tropical grass was absent and it is expected that the values for legume herbage mass may be lower, in particular under low rainfall conditions where competition between grass and legume for water becomes critical. Whether differences in seasonal growth between temperate legumes can be exploited as part of composite pasture mix is unknown and will provide a focus for continuing studies. Having a legume that can provide a consistent growth under varying seasonal conditions may prove a distinct advantage in central western NSW.

Key words
Cultivar, evaluation, herbage mass

Introduction

The incorporation of legumes into tropical grass pastures offers the potential to reduce nitrogen fertiliser input but also increase the year-round productivity of pastures (Harris *et al*. 2014), resulting in more resilient pasture systems. In central western NSW, the climate is characterised by aseasonal, highly variable, low median annual rainfall (<500 mm). This results in feed gaps that can occur at critical times for livestock enterprises, often being met by supplementary feeding (Moore *et al.* 2009). In central western NSW, lucerne (*Medicago sativa*) has been commonly sown, generally as a pure sward (e.g. Bowman *et al*. 2002) but temperate annual legumes such as *Medicago* spp. are also widely used. However, the development of hard seeded legumes such as biserrula (*Biserrula pelecinus*) and serradella (*Ornithopus* spp.) have shown potential in southern NSW (Hackney *et al*. 2012a,b,c) but their use in central western NSW has not been tested.

A lack of practical agronomic information and the identification of suitable companion legumes in grass/legumes mixes are major factors preventing the broad-scale adoption and use of grass/legume mixed pastures in NSW (McCormick *et al.* 2009). A project funded by Meat and Livestock Australia is currently underway to identify productive, persistent legume companions for tropical grass pastures. Sites are located at Trangie in central western NSW and Manilla and Bingara in North-West NSW. This research will aim to develop management guidelines for tropical pastures (legumes and grasses) in central and northern NSW. In this paper we describe preliminary results for herbage mass production and cover of temperate annual legumes sown at Trangie over the first growing season, following establishment.

Method

The site was located on a brown Chromosol soil at the Trangie Agricultural Institute, Trangie (31^{0}56'18.80 S, 147^{0}56'18.80 E). Twelve months prior to sowing, the site was sprayed three times with glyphosate (2 L/

ha; 450g/L a.i) and cultivated with offset disks 6 weeks prior to sowing digit grass (*Digitaria eriantha*) cv. Premier (1 kg/ha viable seed) in November 2012 using a 6-row single disk seeder. The grass failed to establish due to poor summer rainfall (Table 1) and the site was sprayed again with 2 L/ha glyphosate in February 2013. In June 2013, 16 temperate legumes (Table 2) and two non-legume treatments (50 kg nitrogen (N)/ha and nil N controls) were sown at commercial seedling rates (Table 2) into three replicated plots in a spatially balanced design using the same single disk seeder. Plots were 1.5 x 6.7 m with a 0.3-0.5 m buffer around each plot. All legumes established and set seed in the establishment year. Digit grass was resown in October 2013 and again failed leaving the plots as pure legume. In early March 2014 and mid-July 2014, the experiment was sprayed with 820 mL/ha with fluazifop-P (128 g/L a.i) to control annual ryegrass (*Lolium rigidum*). Superphosphate (8.8% phosphorus, 11% sulphur) was applied at 100 kg/ha in mid-May and July 2014.

Herbage mass of legumes within each plot was determined using a modified comparative yield method (Lodge and Harden 2011) at approximately 6 weekly intervals between mid-May and late October 2014. All plots were cut to 5 cm after the first measurement in May 2014 using a rotary mower with a catcher and herbage removed from the plots. Cover was estimated by counting the number of cells that contained sown legume in a permanent quadrat (1 x 1 m, subdivided into 100 cells) located within each plot. Three quadrats were located over the centre four rows within each plot and cover was measured on four occasions; mid-October 2013, mid-May, July 2014 and late August 2014. These measurements provided an indication of recruitment and habit of individual legumes. Dry matter (DM) was modelled for each time period using the mixed linear model DM ~ Variety + random (Rep) + **R,** where **R** is a covariance matrix which includes autoregressive terms for row and column, where appropriate. In addition to this the dry matter values from all time periods were combined into a single dataset and analysed using the mixed linear model, DM ~ Variety + Time + random (Rep + spl (Time)) + **R** where **R** = **T** (time) □ **R** (row) □ **C** (column) is a covariance matrix which includes covariance matrices for time period as well as autoregressive matrices for row and column, where appropriate. The random spline term is used to model non-linear changes in dry weight over time.

Results and Discussion

Significant (P<0.001) differences in predicted dry matter (DM) were found between cultivars (Figure 1). The best performing cultivars were the barrel medics (cvv. Caliph and Jester) and woolly pod vetch (cv. Haymaker) that achieved an equivalent of 1,952 kg DM/ha, 1,632 kg DM/ha and 1,058 kg DM/ha, respectively, in early spring. We also observed that these legumes also had seedling regeneration densities ranging 146-233 plants/m^2. Barrel medic has had a long history of use within central western NSW (e.g. Michalk and Beale 1976) and its winter dominant growth has the potential to provide seasonal complementary, quality feed within a tropical grass pasture (Clarkson *et al*. 1991). These three legumes also provided the highest cover exceeding 66% at each assessment (Table 2). Seasonal patterns of growth indicate peak production for barrel medics cvv. Caliph and Jester occurred over winter but woolly pod vetch reached highest production in early spring, and snail medic cv. Silver in mid spring (equivalent to 522 kg DM/ha). This suggests there may be opportunities for exploiting differences in growth patterns within legume mixes.

Table 1. Monthly and long term average (LTA) and median (LTM) monthly rainfall (mm) at the Trangie site (Bureau of Meteorology site number: 051049, 1922-2014).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2012	81.4	63.0	119.4	3.2	35.6	25.4	31.2	0.4	23.4	8.0	25.0	5.2	421.2
2013	9.6	22.4	57.4	0.0	17.0	107.4	25.4	6.0	55.0	3.2	2.0	31.6	337.0
2014	29.4	58.4	80.0	34.0	11.8	57.4	34.0	34.0	9.8	2.6	6.2	79.6	437.2
LTA	53.5	52.1	47.4	39.2	37.4	35.9	34.3	32.1	31.5	45.8	45.6	41.1	495.4
LTM	39.0	31.1	26.7	23.2	31.5	28.2	30.6	25.7	23.7	35.5	36.4	33.0	470.5

There were a number of relatively unproductive cultivars, producing equivalent to <199 kg DM/ha; French serradella cv. Margurita, Persian clover cv. Nitro Plus and purple clover cv. Electra. These legumes also had low regeneration plant densities (<20 plants/m^2). This is surprising as there have been some reports of successful stands of purple clover, albeit east of Trangie, however adaptive differences between species and cultivars to site characteristics such as soil will be examined using on-going multiple site experiments. It may be that poor performance was linked to low seed production (all species set seed, but seed yields were

not recorded) and/or a decline in rhizobia numbers over the course of the experiment especially since plant numbers have declined each year. Although all legumes were inoculated with recommended rhizobia strains, and nodules were found on plants in the establishment year, biserrula and serradella both have specific rhizobia strains requirements (Hackney *et al*. 2012a,c).

Table 2. Sowing rate (kg/ha viable seed) and cover (%) of 16 temperate annual legumes sown at Trangie Agricultural Research Centre.

Temperate legume and cultivar	Sowing rate (kg/ha)	Cover (%)			
		17/10/13	19/05/14	14/07/14	27/08/14
Arrowleaf clover (*Trifolium vesiculosum*) cv. Cefalu	1	55.0	40.6	45.8	43.1
Barrel medic (*Medicago truncatula*) cv. Caliph	5	88.9	74.5	79.7	77.0
Barrel medic cv. Jester	2	81.4	67.0	72.2	69.5
Biserrula (*Biserrula pelecinus*) cv. Casbah	1.5	49.0	34.6	39.8	37.1
Bladder clover (*T. spumosum*) cv. Agwest Bartolo	3	37.8	23.4	28.6	25.9
French serradella (*Ornithopus sativus*) cv. Margurita	1.5	28.8	14.4	19.6	16.9
Gland clover (*T. glanduliferum*) cv. Prima	2	35.9	21.4	26.7	24.0
Persian clover (*T. resupinatum*) cv. Nitro Plus	1	13.0	0.0	3.9	1.1
Purple clover (*T. purpureum*) cv. Electra	1	40.1	25.6	30.9	28.2
Rose clover (*T. hirtum*) cv. SARDI Rose	1	24.9	10.5	15.7	13.0
Snail medic (*M. scutellata*) cv. Silver	7	50.0	35.5	40.8	38.1
Subterranean clover (*T. subterraneum*) cv. Campeda	3	45.1	30.6	35.9	33.2
Subterranean clover cv. Dalkeith	10	46.0	31.5	36.8	34.1
Woolly pod vetch (*Vicia villosa*) cv. Capello	6	81.3	66.9	72.1	69.4
Woolly pod vetch cv. Haymaker	6	90.6	76.2	81.4	78.7
Yellow serradella (*O. compressus*) cv. Santorini	3.5	65.5	51.1	56.3	53.6

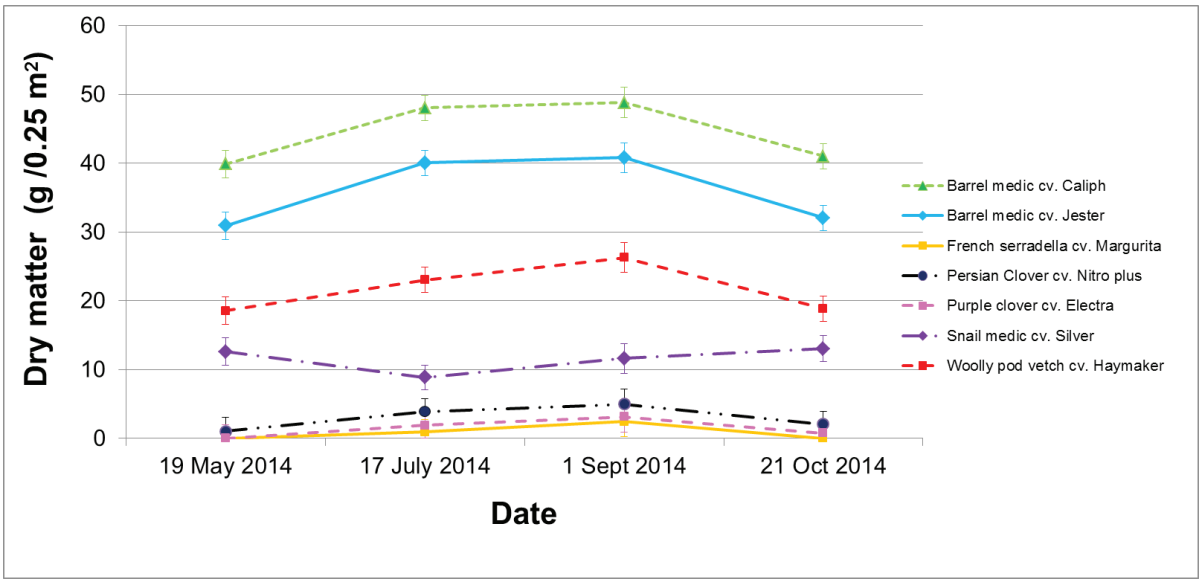

Fig. 1. Seasonal patterns in mean predicted dry matter production (g/0.25²) and standard error for a selection of cultivars.

Seasonal rainfall variation has a significant impact on annual pastures, especially in the more arid western NSW. The success of temperate annual legumes initially depends on sufficient rainfall for establishment and finally sufficient rainfall for seed set. Smith and Cooper (1996) determined that the probability of rain exceeding 25 mm in each month during April and May (establishment) at Trangie ranged 0.47-0.55. In September (flowering and seed set), the probability of >25 mm rainfall was 0.49. Maintaining a seed bank is essential to the long term persistence of annual legume and a large seed bank provides 'insurance' for years unfavourable for annual legumes. The inability to successfully establish digit grass sown in mid- October/ November at this location suggests that an early spring sowing (possibly September) may prove a better option for central western NSW.

Conclusion

Although this is an ongoing study, it appears there are useful levels of variation in seasonal growth patterns that may provide opportunities for legume mixes and complementarity with tropical grass pastures. The ability for these species to produce a second season of production will be based on a capacity for cultivars to set seed to produce a sufficient seedbank. To-date, the results highlight a superiority of the medics and potential of woolly pod vetch in central western NSW.

Acknowledgement

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Nitrogen fertiliser may pay on tropical grass pastures

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Low productivity in sown grass pastures due to a lack of available soil nitrogen can reduce beef production by up to 50% across Queensland. The feasibility of strategic nitrogen (N) fertiliser applications to address these losses was assessed by desktop analyses using data from published studies, local fertiliser trials and expert opinion. These analyses suggest that applying nitrogen to rundown sown grass pastures can produce dramatic increases in dry matter yield and animal production. However, high and consistent response rates in pasture productivity, stocking rates and growth rate of cattle were required for the application of nitrogen fertiliser to be profitable. For the suggested 100 kg N/ha fertiliser rate: average gross margins in the year of application were calculated to increase by 121-217% when dry matter yield responses of 40 kg DM/kg N (i.e. an additional 4000 kg/ha) and an additional liveweight gain of 0.2 kg per adult equivalent (AE)/day can be achieved (i.e. an extra 70 kg AE/year). These economics were very sensitive to the assumed response rates in pasture growth, stocking rate and liveweight gain and did not account for uncertainty in climate and beef prices. New research is proposed to re-assess the responses used in this analysis that are largely based on research 25-40 years ago when soils were generally more fertile and pastures less rundown.

Key words
Sown pasture degradation, sown pasture rundown, nitrogen, dry matter production

Introduction

Sown pastures can produce more feed, of better quality, for longer periods of time than native pastures alone. Since the 1970s, sown pastures have been established on approximately 12 million ha across northern Australia, mostly in Queensland (Peck *et al*. 2011), to improve production and economic returns for the beef industry (Walker *et al*. 1997). These sown pastures and forages underpin up to $1.4 billion per annum of beef production in the 'Mixed farming zone' of southern and central Queensland and represents approximately 40% of Queensland's total beef output. Many of these pastures have suffered declines of up to 50% in pasture productivity caused by a lack of available soil nitrogen as pastures age (Graham *et a*l. 1981). The mineral nitrogen in these aging pastures becomes immobilised in the established grass plants and soil organic matter (Graham et al. 1985). While this pasture degradation (or rundown) affects all grass and grass-legume pastures, it is most severe in the grass-only pastures that represent up to 70% of the total area planted in Queensland (Walker *et al*. 1997).

The effects of rundown can be mitigated by increasing the nitrogen supply to the soil with either fertilisers or legumes. There is wide industry consensus that adapted legumes provide the best option to improve productivity of rundown sown grass pastures (Peck *et al*. 2013). Legumes provide good returns on capital investment as long as they can be successfully established (Ash *et al*. 2013). However, most graziers use high-risk establishment methods with little ground preparation. Subsequent establishment failures have led to the perception that legumes are difficult to establish and has renewed interest in nitrogen fertilisers that are more reliable and easy to apply.

Commercial use of nitrogen fertilisers to promote pasture yields in Queensland is limited, and advisers have used a generalised 'response rate' of 30 kg dry matter (DM) for every kilogram of nitrogen (N) applied (Graham *et al*. 1981). However, 'response rates' of up to 60 kg DM/kg N have been measured in recent research across Queensland (Lawrence et al. unpublished data). This paper, based on desktop analyses, evaluated the possible impact of these higher response rates on beef productivity and economic returns.

Method

The project developed a range of generalised scenarios to assess possible total DM production for selected pastures, stocking rate increases, liveweight gains and estimated gross margins for a range of fertiliser response rate to a single 'one-off' fertiliser application only. While on-going trials suggest that larger DM responses may be possible from repeated applications, the lack of available data precluded further analyses. All responses are static averages and do not include the effects of seasonal variation.

Pasture scenarios
Two hypothetical buffel grass pastures were investigated; one with lower DM production (3000 kg DM/ha/yr), another with higher DM production (4500 kg DM/ha/yr) to represent the range of rundown pastures in Queensland. Nitrogen fertiliser was assessed at 100 kg N/ha applied as urea to reflect the practices of those graziers currently using nitrogen fertilisers. A 'half-rate' of 50 kg N/ha was also included to assess the likely impact of using a lower rate over a larger area on the property. Urea contains 46% nitrogen and was costed at $700 per ton delivered to the property. Both rates were applied by a fertiliser spreader with the same application costs. Pasture response rates of 20-50 kg DM/kg N were included to allow for higher and lower responses that may be expected due to different combinations of location, soils and climate, along with the seasonal conditions and the underlying level of rundown in each pasture.

Animal production and carry capacity

Table 1. Parameters for an unfertilised buffel grass pasture producing 3000 or 4000 kg DM/ha/yr

Pasture production (kg DM/ha/yr)	3000	4500
Forage consumed (kg DM/ha/yr)	750	1350
Forage spoiled (kg DM/ha/yr)	450	900
Residual forage (kg DM/ha/yr)	1800	2250
Forage utilisation (%)	25	30
Stocking rate (AE/ha)	0.21	0.37
Liveweight gain (kg/AE/yr)	150	150
Beef production (kg/ha/yr)	31	56

Animal production was estimated on the initial 'baseline' unfertilised pastures (Table 1). Initial stocking rates were calculated as hectares per Adult Equivalent (AE, a dry animal of 450 kg liveweight (LW)). The subsequent economic analysis used the average weight of stock over the grazing period to account for their growth while on a 100 ha pasture. Average DM intake per AE was estimated at 2.2% of LW over the year, i.e. 10 kg DM/day or 3650 kg DM/yr. Stocking rate was derived by dividing 3650 by the forage consumed (kg DM/ha/yr) by the estimated intake by an AE (3650 kg DM/yr).

Two parameters were increased in response to fertilisation. The spoilage of forage increased with additional pasture production (15% <4500 kg DM/ha; 20% 4501-7500 kg DM/ha; 25% >7500 kg DM/ha), and liveweight gain (LWG) was increased in two scenarios for each fertiliser rate, that is 0.05 or 0.1 kg/AE/day with 50 kg N/ha, and 0.1 or 0.2 kg/AE/day with 100 kg N/ha.

Economic assessment
The paddock level enterprise modelled in this analysis was a trading enterprise in the southern Brigalow belt of central Queensland that purchased store steers and sold finished Ox direct to the meatworks. The boundaries of the enterprise were the physical paddock boundaries. The only expenses incurred by the paddock enterprise were those that varied with the number of cattle run in the paddock, such as husbandry and selling costs. An allowance was made for the amount of additional effort and cost required to apply the fertiliser. The enterprise budgets were compiled in the form of paddock gross margins and were used to identify the profitability of differing levels of fertiliser response within paddocks. Stock were purchased at $1.64/kg and sold at $1.66/kg reflecting the small historical margins in the market and the prices expected at the time. Full details of the economic assessment are contained in Chudleigh (2013).

Estimating relative profit at the paddock level using a gross margin format allowed the costs and incomes associated with the remainder of the business, that do not change with a change in fertiliser use, to be ignored, thereby simplifying the analysis.

Results and discussion
The modelled average increase in beef production per hectare from 100 kg N/ha ranged from 170% up to 721%, and based on the model assumptions, the relative increases were greater when higher response rates in forage yield and/or LWG per steer were used. While a comprehensive coverage of all scenarios is beyond the scope of this paper, several selected scenarios provide insight into the likely impacts.

It has been assumed that pastures that remain in good condition (e.g. with a good density of plants) will respond to applied nitrogen at a rate of around 40 kg DM/kg N. Using this response rate 100 kg N/ha was calculated to increase beef production by 210-250 kg/ha on the more productive 4500 kg DM/yr pasture (Table 2). The increases were smaller on the less productive 3000 kg DM/ha pasture but produced higher relative increases. The lower rate of 50 kg N/ha was also estimated to provide lower increases in beef production of 102 to 115 kg/ha/yr. Table 2 summarises the impacts of the different assumptions with the suggested 100 kgN/ha application to a rundown pasture in a favourable district that produces 4500 kg DM/ha/yr on average.

Table 2. Average beef production increase due to 100 kg N/ha fertiliser with extra liveweights gains of 0.1 to 0.2 kilograms per AE per day and a range of 20 to 50 kg extra dry matter per kg of N applied

Base pasture (4500 kg DM/yr)	**LWG 0.1 kilograms/AE per day**				**LWG 0.2 kilograms/AE per day**			
Pasture response (kg DM/kg N)	**20**	**30**	**40**	**50**	**20**	**30**	**40**	**50**
Extra pasture growth (kg DM/ha/yr)	2000	3000	4000	5000	2000	3000	4000	5000
Forage spoiled (kg DM/ha/yr)	1300	1500	2125	2375	1300	1500	2125	2375
Residual forage (kg DM/ha/yr)	2250	2250	2250	2250	2250	2250	2250	2250
Forage consumed (kg DM/ha/yr)	2950	3750	4125	4875	2950	3750	4125	4875
Stocking rate (AE/ha)	0.81	1.03	1.13	1.34	0.81	1.03	1.13	1.34
New LWG (kg/AE/yr)	185	185	185	185	220	220	220	220
Extra LWG (kg/ha/yr)	150	190	209	247	178	226	249	294

The gross margin for this 100 kg N/ha application on the 4500 kg DM pasture again varied with the fertiliser response rates and LWGs. The expected fertiliser response rate of 40 kg DM/kg N boosted the gross margin from $52 to $115 /ha when a high extra LWG (0.2 kg/AE/day) was assumed (Figure 1). However, if the extra LWG was only 0.1 kg/AE/day, the gross margin fell to $36/ha, and was even worse at $18/ha when the traditional response rate of 30 kg DM/kg N was assumed (Chudleigh 2013). Further analysis not reported here estimated that Internal Rate of Return of 11% was possible for the same dry matter response rate of 40 kg/kg N rate if potential carryover nitrogen responses were included in subsequent years and the additional LWG was more conservatively spread across two years (50 kg/AE in the first year and 20 kg/AE in the second year).

These figures suggest that nitrogen fertiliser has the potential to increase gross margins where the fertiliser impacts significantly on both stocking rates and LWGs. However, it is clear that the use of nitrogen fertiliser may also lose money if the response rate is below 30 kg DM/ha or the additional liveweight gains are low. It should also be remembered that these analyses were based on average figures without the additional risks from seasonal variability or price variation.

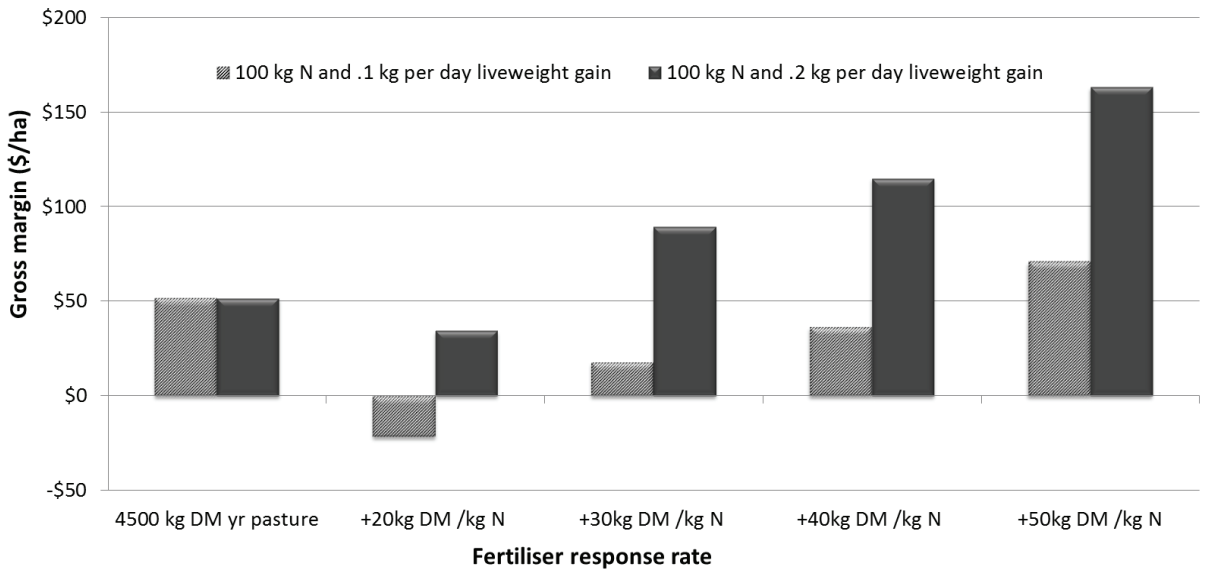

Figure 1. Average gross margins when 100 kg N was applied to a pasture producing 4500 kg DM/ha/yr and livestock having a LWG of 0.1-0.2 kg/AE/day

The analysis highlights the sensitivity of beef production and profitability to the underlying assumptions on the fertiliser response rate and the additional liveweight gains that can be achieved. The economic analysis also highlights that the impressive increases in beef production require a large additional investment in stock numbers and this investment reduces the economic returns, especially when stock are all purchased as they were in the simple scenarios studied here.

Conclusions

The desktop scenario analyses in this study suggest that applying nitrogen fertilisers to rundown sown grass pastures will produce dramatic increases in DM production and animal productivity. However, a relatively high and consistent response rate in both pasture yield and quality, and hence per head and per hectare livestock production, was required for any reasonable likelihood of the application of nitrogen fertiliser being profitable.

The analyses in the project were largely based on average results and did not include any variability in seasonal conditions. Seasonal variability will increase risk in these fertiliser scenarios, or indeed, any effort to intensify production in the beef industry. For fertiliser, these risks may be managed by restricting applications to seasons in which conditions are already good and avoiding applications in dry seasons, or seasons with the prospect for continuing low rainfall.

Recent trials and reviews of past research suggest a 40 kg DM/kg N response rate is achievable. However, the economic analyses suggest that this need to be coupled with large improvements in weight gain per head for beef producers to be better off. Lower DM response rates and LWGs will fail to provide major benefits, or lose money. Much of the research on pasture rundown, fertiliser responses and LWGs was done over 30 years ago, and most likely on less 'rundown' pastures. New research is now needed to clarify the anecdotal evidence of higher DM responses and to see if they can be converted into profitable livestock responses.

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Is summer sowing as effective as winter sowing for introducing serradella into subtropical perennial grass pastures?

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Abstract
This experiment compared the performance of serradella (*French, Ornithopus* sativus; and yellow, *O. compressus*) sown into established perennial grass pastures in summer (February) using dormant pod segments (new summer sowing technology), with serradella sown into perennial grasses after the break of season using scarified seed (traditional method). Even though serradella summer sown into Gatton panic (*Megathyrsus maximu*s) had significantly lower seedling numbers compared to serradella summer sown into plots without perennials (25% less), serradella biomass and seed production was greater (92% more seed-set). Seed production in perennial grass plots was also significantly greater ($P<0.001$) in summer compared to winter sown plots (40% more). Overall, winter biomass production was highest in plots without a perennial base but the pastures were dominated by capeweed (*Arctotheca calendula*). Yellow serradella, experimental line 87GEH72.1a, flowered earlier than Margurita[A] French serradella, but produced similar amounts of biomass and seed overall, and appeared well suited as a companion annual legume. Summer sowing serradella pod-segments was as effective as winter sowing scarified seed for introducing a companion annual legume into subtropical perennial grass pastures.

Key words
Perennial pasture, Evercrop project

Introduction

About 50,000 ha of subtropical perennial grasses have been sown across deep sandy soils in the Northern Agricultural Region (NAR) of Western Australia (Larson and Howard, 2013). Benefits include year-round groundcover, reduced deep drainage, green feed over summer and increased animal production; however, there are concerns about the ongoing productivity of perennial grass pastures due to low or no annual legume content and inadequate nutrition (Dolling *et al*., 2015).

French serradella (*Ornithopus sativus*) and yellow serradella (*O. compressus*) are annual legumes well adapted to deep sandy soils and could be used as a companion annual legume to improve feed quality and drive the productivity of subtropical perennial grass pastures; however, sowing annual pastures immediately after the break of season often conflicts with demands of large annual cropping programs. Consequently, many annual legume pastures are sown late, under conditions too cold to promote rapid growth and good establishment. Loi et al. (2012) are promoting summer sowing as a way to establish hard-seeded annual pasture legumes without interfering with cropping operations. Summer sowing is a new technology where dormant, un-scarified, pasture-legume seeds (or pod segments) are sown in early summer; a high proportion of these seeds gradually soften over the summer-autumn period (3-4 months) and are ready to germinate at the break of season (Loi *et al*., 2012).

The aims of this study were (a) to compare the performance of serradella sown into established subtropical perennial pastures in summer (February) using pod segments, with serradella sown into perennial grasses after the break of season using scarified seed; (b) to evaluate the impact of a perennial base and herbicide suppression on serradella establishment, biomass production and seed yield

Materials and Methods

Site history & treatments

In 2011, perennial pasture plots (7 x 20 m) were established at 29° 12’ 30”S, 115° 10’ 32”E on a non-wetting, deep sandy soil 25 km west of Mingenew, using precision guidance technology (DGPS ± 2 cm accuracy)

and auto-steer. The site was originally set up to evaluate the viability of pasture cropping across Gatton panic (*Megathyrsus maximus*; rows 44 cm apart). In 2014, the 30 plots were re-allocated to seven pasture improvement treatments (Table 1). The new trial had a criss-cross design: seven main pasture improvement treatments and 2 herbicide treatments (± suppression) applied at right angles across these (14 treatments in total).

Table 1. Pasture improvement treatments

Trt*	Reps	Description – main pasture treatments (variety, sowing time/perennial)
1	4	Perennial grass control (i.e. no serradella)
2	3	87GEH72.1a Yellow serradella - summer sown into annual plots (i.e. no perennial grass)
3	3	Margurita[A] French serrardella - summer sown into annual plots (i.e. no perennial grass)
4	5	87GEH72.1a Yellow serradella - summer sown into perennial grass
5	5	Margurita[A] French serrardella - summer sown into perennial grass
6	5	87GEH72.1a Yellow serradella - winter sown into perennial grass

* The perennial grass was a 2.5 year old Gatton panic stand (Megathyrsus maximus); A grass selective herbicide was sprayed across half of each plot at a right angle to the main treatments.

Seeding & management inputs

French serradella (MarguritaA) and an experimental line of yellow serradella 87GEH72.1a (with a similar softening pattern to MarguritaA) were sown between perennial rows or into annual plots with a cone seeder (tines 22 cm apart) using precision guidance technology. Dormant pod segments were summer-sown into plots on 20 February (20 kg pod/ha plus 10 kg/ha ALOSCA®); and scarified seed was winter sown into plots on 21 May (7 kg seed/ha plus 10 kg/ha ALOSCA®) after a knockdown spray (540g/L glyphosate at 0.75 L/ha). Fertiliser (160 kg/ha Big Phos, N 13.5%, S 7.5%, Ca 18%) was top-dressed across all plots at seeding.

The trial was sprayed (21 May) with Broadstrike® (800 g/kg Flumetsulam at 25 g/ha) to control volunteer narrow-leafed lupins and broad-leafed weeds; and Select® (240 g/L clethodim at 500 mL/ha) was sprayed on 4 July across half of each plot to suppress the perennial grasses. A ride on lawn mower (cutting height ~8 cm) was used to simulate grazing just before winter seeding and immediately after biomass assessments on 25 June and 7 August.

Assessments & analyses

Serradella establishment was assessed in summer sown plots on 15 May and winter sown plots on 11 June (three weeks after seeding) by counting the number of seedlings long 1 m long rows at 8 random positions per plot. Biomass growth was assessed by sampling three 0.44 m^2 quadrats per plot on 25 June and 7 August; and following the application of Select, two quadrats per sub-plot on 27 August and 6 November. Serradella seed production was estimated by collecting pods from within three 0.2 m^2 quadrats per sub-plot and by assuming a seed to pod ratio of 63% for MarguritaA and 36% for 87GEH72.1a.

The impact of the three main factors (variety, sowing time/perennial and suppression) on serradella and total biomass (both cumulative to 27 August) and serradella seed production was analyzed by fitting linear mixed models using REML (residual maximum likelihood) to take into account the unbalanced strip plot structure of the design. The factor sowing time/perennial has factor levels of summer sowing with no perennial, summer sowing into perennial and winter sowing into perennial. In the case of total biomass there is also a forth factor level of no serradella. Analysis of germination data was simplified because the suppression treatment had not yet been applied so analysis of variance was used. All analysis was done in GenStat version 17.

Results

Germination and establishment

There was a decisive break to the growing season in 2014 in late April and good follow-up rains: overall the site received 56 mm in April and 54 mm in May. This promoted even germination and early winter biomass production in all plots. Notwithstanding, there were significant main effects for variety (P=0.004) and sowing time/perennial (P=0.035). When serradella was summer sown into annual plots at 20 kg/ha pod (i.e. no perennials), MarguritaA produced 149 plants m^2, while 87GEH72.1a only produced 79 plants m^2, possibly

due to a lower seed to pod ratio. Summer sowing MarguritaA into perennials instead of annual plots, resulted in 32% less seedlings, possibly due to increased competition. Establishment density was similar (average 113 plants m^2) for both species when sown in winter at 10 kg/ha of scarified seed.

Biomass production

For total cumulative biomass to 27 August, there was a highly significant effect of sowing time/perennial ($P<0.001$). However, the main effects of suppression and variety were not significant. The annual only plots produced the most total biomass (4.2 t/ha) but these were dominated by capeweed (*Arctotheca calendula*). By contrast, there were fewer weeds in all subtropical perennial grass plots. Perennial plots winter sown with serradella produced 2.2 t/ha which was not significantly different to the amount of biomass produced in perennial only plots (1.9 t/ha); by contrast summer sowing serradella into perennial grass plots increased total winter biomass by 42% (Figure 1).

In relation to serradella biomass, the main effect of suppression was not significant, but there were significant main effects of variety ($p<0.001$) and sowing time/perennial ($p<0.001$). Summer sowing serradella into perennial grass plots resulted in significantly higher serradella biomass than summer sown into no perennial, which in turn was significantly higher than winter sown into perennial. MarguritaA produced 550 kg/ha more winter biomass than GEH72.1a up until 27 August (averaged over all treatments). By the end of the winter growing season (November), legume biomass had almost doubled (av. 2.0 t/ha) due to rapid growth in spring.

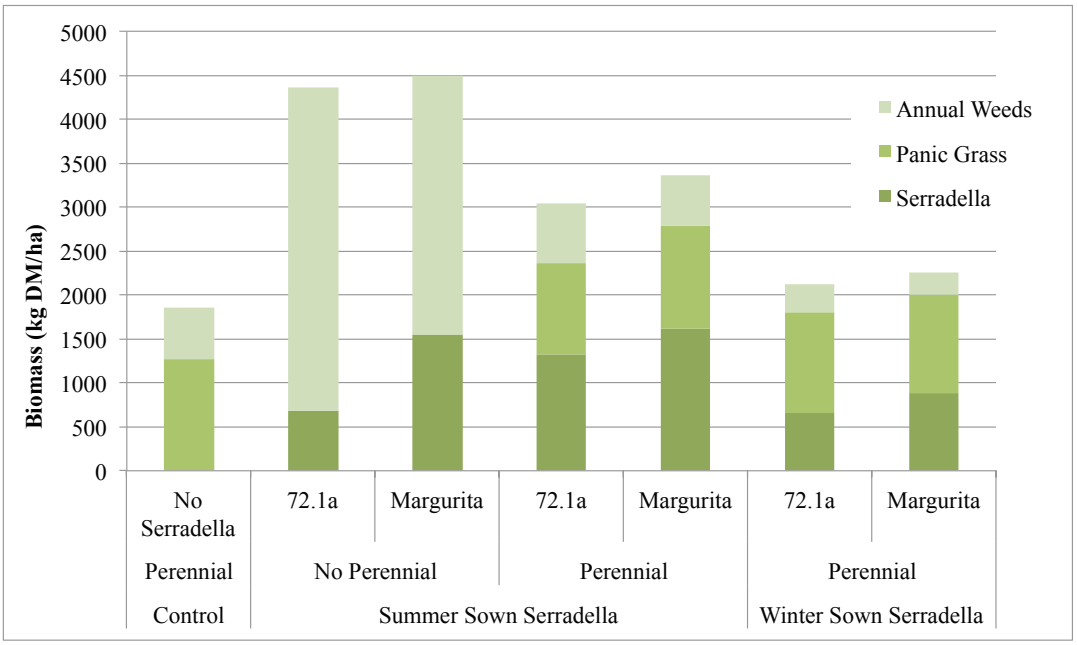

Figure 1. Cumulative biomass and pasture composition for pasture improvement treatments 87GEH72.1a (72.1a) and Margurita[A] up to 27August (Treatment 1 to 7, Table 1; Average LSD = 673 kg/ha for total biomass and 410 kg/ha for serradella biomass)

Serradella seed production

There was a highly significant effect of sowing time/perennial ($P<0.001$): summer sowing into perennials had significantly higher serradella seed production compared to winter sown into perennials. The main effect of suppression was not significant; however, there was a significant interaction of suppression with sowing time/perennial ($P=0.023$) reflecting that suppression had a positive effect when sowing into perennial but negative effect when sowing into no perennial. For summer sowing into perennial with suppression, MarguritaA produced 460 kg/ha and 87GEH72.1a 560 kg/ha of seed (Figure 2).

Discussion

This study found that establishing serradella in a subtropical perennial grass pasture can be done successfully by either sowing pod segments in summer or sowing scarified seed in winter. Summer sowing and a decisive break enabled serradella to germinate earlier and take advantage of a longer growing period (~3 weeks) compared to traditional winter sowing; and seedling emergence was uniform for all summer sown treatments

irrespective of the perennial base. By contrast, seedling emergence in perennial plots was delayed in a preliminary study at Dandaragan (Valentine *et al*., 2014). In that trial, sparse rainfall events in April were only sufficient to boost serradella growth in annual only plots. Serradella sown into plots without perennial gasses did not set as much seed as serradella sown into perennial plots due to greater weed competition. By contrast Valentine *et a*l. (2014) reported 24-43% reduction in serradella seed yield when sown into perennials, but that trial had fewer annual weeds and earlier germination in annual only plots. Even though Select® suppressed the growth of Gatton panic, the benefits to serradella performance were not as high as anticipated. In winter sown plots, a glyphosate knockdown also suppressed the perennials and likely accounts for the grass selective only promoting additional seed set where serradella was summer sown into perennial plots. These results indicate that herbicide suppression is not necessarily needed to establish an adequate seed bank for dense serradella regeneration in subsequent years. The experimental line of yellow serradella 87GEH72.1a was a prolific seed producer and appears well suited as a companion annual legume for subtropical perennial grass pastures in the medium rainfall zone of the Northern Agricultural Region.

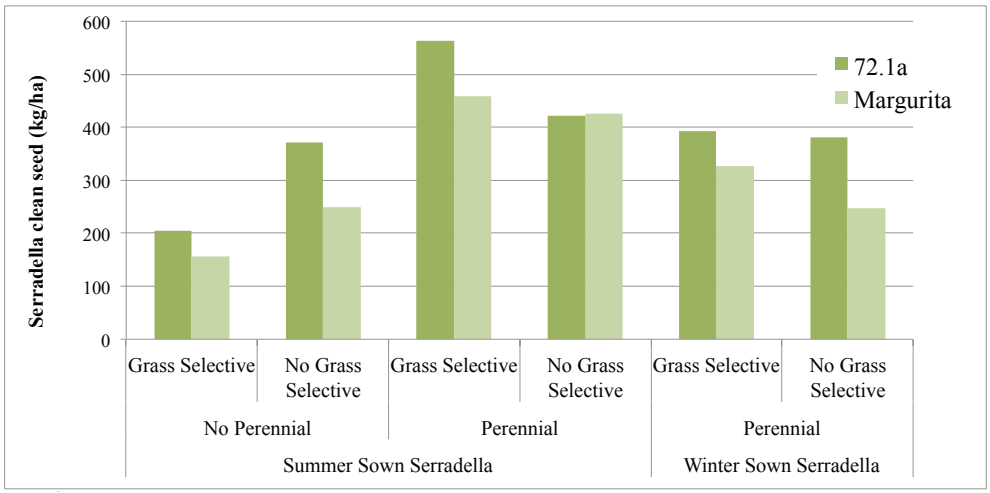

Figure 2. Impact of time of sowing, perennial grass and grass suppression on seed yield of 87GEH72.1a (72.1a) and Margurita[A] serradella (Treatment 2 to 7 ± grass selective, Table 1; Average LSD =187).

Conclusion

Summer sowing serradella pod-segments is an effective technique for introducing a companion annual legume into subtropical perennial grass pastures. However, the success of summer sowing in different years and sites might be influenced by the decisiveness of the break of season, the annual weed burden and the density and/or level of activity of the perennial pasture. Summer sowing could provide a cheaper, more convenient and timely method to establish a companion legume than traditional winter sowing.

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An analysis of R, D & E needs of cropping rotations with kikuyu pastures on the south coast of Western Australia

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Abstract
Kikuyu pastures have been grown along the south coast of Western Australia for over 70 years to stabilize sandy surface soils and lift the productivity of cattle and sheep enterprises. In more recent times, some of these perennial pastures have been cropped. Our aim was to determine research and extension needs for this emerging technology. We conducted nine interviews with consultants, agronomists and farmers involved in cropping kikuyu pastures. The respondents indicated that about 150,000 ha of perennial pastures are grown along the south coast, mainly above the 450 mm rainfall isohyet, and that most of the perennials are kikuyu. Key issues were the build-up of thatch and silver grass over time, as both reduce the productivity of kikuyu pastures. The main reasons for cropping kikuyu pastures were to rejuvenate stands and to obtain a cash crop. The survey revealed that there are two general approaches used to crop over kikuyu: one system tries to kill (lethal) and the other tries to suppress (sub-lethal) the kikuyu stand with herbicides. The main research and extension needs are: an economic analysis of both systems, highlighting the trade-offs between cropping and livestock industries; guidelines on the timing of herbicide application before cropping, in relation to mineralization rate and nutrient release; and field data to quantify how quickly kikuyu re-establishes after a cropping phase and subsequent productivity compared to permanent pasture.

Key words
Kikuyu, pasture cropping, nutrient release, EverCrop

Introduction
Kikuyu (*Pennisetum clandestinum*) was introduced into Western Australia in the mid-1920s and has proved to be well adapted to the high rainfall zone in the south-west of WA. The South Coast region receives on average 400 to >750 mm of annual rainfall, has no or low incidence of frost, cool winters, mild springs, a medium to long growing season (6-8 months) and warm to hot summers with 25-35% of rain falling outside the winter growing season (Moore 2006). Kikuyu is well adapted to these conditions and the deep sands which are wide-spread along the south coast. Not only does kikuyu increase the productivity of these soils it also stabilizes the soil and prevents wind erosion.

Establishing kikuyu with subterranean clover has enabled stocking rates to be increased by 65-95% compared with pastures based on subterranean clover alone (Sanford 2003). However, this increase in productivity is dependent on managing the kikuyu stand so that pasture quality does not decline. Maintaining feed quality is very dependent on promoting the growth of new kikuyu leaves and persistence of the subterranean clover base (McDowall 2003). Farmers have found that the productivity and feed quality of their kikuyu pastures is declining over time as thatch and silver grass build up and the density of subterranean clover declines due to the development of very high kikuyu densities combined with false breaks. Cropping these stands has emerged recently as a way to both rejuvenate pastures and obtain a cash crop. This social science study was conducted to capture the experiences and perceptions of those involved in cropping into kikuyu pastures and to determine research and extension needs to inform a GRDC funded project (EverCrop).

Method
The study involved interviewing nine farmers, consultants, agronomists or research staff involved in advising clients or researching perennial pastures and pasture cropping. There were nine questions asked about perennials (area, species, and potential for expansion) and pasture cropping (experience, approach, advantages, problems, potential for expansion, and RD&E needs) on the south coast. The participants were either interviewed in person or they filled the questionnaire out independently.

Results and discussion

Regional context

The overall area of perennials grown on the south coast was estimated to be around 150,000 ha of which at least 100,000 ha is kikuyu. Other perennials include about 10% lucerne and 10% temperate grasses, chicory, other sub-tropical grasses and saltland pastures. In Esperance, the area of kikuyu was estimated to be between 8,000 and 20,000 ha. In the south coast region, kikuyu pastures are located predominately in the greater than 450 mm rainfall zone in a 50-75 km strip following the coast.

Most respondents thought that there was potential for the expansion of kikuyu and other perennials with higher feed quality. Pasture cropping is one possible driver for expansion. However, one respondent thought that, at least around Esperance, there was not much opportunity in the short term due to the higher relative profitability of cropping compared to livestock. Observations along the entire south coast appear to support this view that cropping is encroaching on areas that traditionally supported kikuyu and other pastures (rather than crops).

Pasture cropping systems

The survey revealed that there is a wide range of cropping systems practiced. At one end of the spectrum a sub-lethal dose of herbicide is applied just before seeding to suppress kikuyu pastures; this reduces competition between the annual crop and perennial pasture during the crop year and enables the pasture to regenerate from stolons after harvest. At the other end of the spectrum a lethal dose of herbicide is applied well before seeding to kill kikuyu pastures, and the ground cultivated multiple times to break up the thatch layer. Cultivation increases mineralization of pasture residues over 1-2 years of crop, but means kikuyu must regenerate from a much lower density (stolons and/or hard seed reserves).

The main drivers of the sub-lethal, pasture cropping system are: the need to renovate old kikuyu pastures (i.e. reduce thatch, control silver grass and improve annual legume content) and crop income. In addition, if lupins are grown farmers value the flow-on benefits of fixed nitrogen to regenerating kikuyu pastures. Advantages of the sub-lethal system include: maximising pasture production before cropping, as the late herbicide application enables growth after any summer or early autumn rains and a quicker response to summer and autumn rains following harvest compared to the lethal system, because stolons are still dense and well established. Disadvantages of the system can be: a lower soil moisture content at seeding; insufficient time for kikuyu residues to break down, making paddocks rough after seeding; and competition between crop and kikuyu plants during grain fill, which can result in a yield penalty. Overall, this system suits more livestock orientated farmers seeking to improve the performance of their kikuyu pastures; and any return from the crop helps to cover the cost of achieving this objective.

The main driver of the lethal system is extra crop income. Rejuvenating the kikuyu base and improving annual legume content are secondary considerations. The lethal system maximises grain yield as there is minimal competition from kikuyu. The system is also thought to release more nutrients for crop growth because there is more time for kikuyu residues to break down. Disadvantages of this system can be: less pasture production in autumn after kikuyu is removed, less pasture growth after harvest because kikuyu must regenerate from a lower density, and more weeds in the subsequent pasture. The system may also require a kikuyu seed bank to enable adequate regeneration after crop; and the rate of kikuyu regeneration is dependent on the amount of summer and autumn rain. In a permanent kikuyu pasture, weeds are suppressed, included melons and thistles in summer, and capeweed and geranium in winter. However, once kikuyu is disturbed or its density declines these weeds become more prominent. Overall, this system suits more cropping orientated farmers seeking to expand their cropping area without exacerbating the threat of wind erosion.

Agronomy and yields

Most farmers use high rates of glyphosate to kill kikuyu or lower rates to severely retard its growth. The rate of glyphosate required to kill kikuyu varies from season to season: 1.5 to 2 L/ha of glyphosate 450 (or equivalent) is generally used. The timing of this knockdown varied from spring (which enables a summer crop), to immediately before seeding a winter crop. Timing depended on personal preference, location and the requirement for summer and autumn feed. The earlier that kikuyu is sprayed the greater the time for thatch and organic matter breakdown, nutrient release and soil water build-up. Respondents indicated that four to six weeks, after spraying, was sufficient time to achieve these benefits. Late removal enables greater pasture growth in summer and autumn for livestock production; it also reduces the risk of waterlogging in a wet year and the risk of wind erosion over summer and autumn.

Cultivation post spraying and before sowing was not common but may hasten the breakdown of kikuyu thatch and increase the release of nutrients. Most farmers seeded directly into decaying kikuyu using narrow points (< 15 mm). Discs have also been used but are not as common as tines.

The survey revealed that farmers believe that yield penalties associated with cropping kikuyu were minimal compared to paddocks cropped without kikuyu. The most frequent crops grown were lupins and canola. Farmers have a preference for these broadleaf crops because in-crop herbicides are available to control annual grasses. Pasture cropping provides an opportunity to control silver grass, in particular, which can become a problem weed in kikuyu pastures. Atrazine and simazine are generally used; however, in dry years their efficacy can be low as kikuyu pastures are often grown on non-wetting soils. Growing broadleaf crops also enables the use of clethodim which not only controls annual grass weeds, but also slows the growth of mature kikuyu plants and kills kikuyu seedlings if required. For the lethal system, cereals are often grown as a second winter crop (after canola) as the density of kikuyu is still low; however, there are limited in-crop herbicides available to control kikuyu in cereals.

The respondents suggested that cropping every 2-3 years may be needed to prevent thatch from developing. Cropping was also seen as a way to improve the nutrient status of kikuyu pastures. Respondents thought that flow on benefits might be derived from nitrogen fixed by lupin crops, inorganic fertilisers applied but not taken up by crops, or nutrients released from the breakdown of organic matter.

Research, development and extension requirements

Currently, little is known about the relative performance, profitability and environmental outcomes of different kikuyu-based cropping-systems along the south coast of WA. There is also inadequate knowledge on the soil water dynamics of different cropping system, the amount of nutrients released from decaying organic matter, and the level of nutrient re-cycling from below the annual crop and pasture root zone. Key questions that need to be addressed in order to evaluate and refine the technology include:

- Can cropping over kikuyu be used as a tool to renovate old kikuyu pastures?
- What is the relative performance of pastures regenerating after lethal versus sub-lethal systems?
- What is the yield and grain quality of crops produced in lethal versus sub-lethal systems?
- To what extent does the timing of kikuyu removal influence crop yield?
- To what extent does cultivation stimulate mineralization and nutrient release to crops?
- What are the trade-offs between crop and livestock components of each system?
- What is the overall profitability of different kikuyu-based cropping-systems?
- Are there any negative environmental outcomes of cropping into kikuyu pastures?

Over the next two years the EverCrop team will work with innovative farmers to compare the productivity of the two general systems by measuring the performance of crops sown across kikuyu pastures and the impact of cropping on subsequent kikuyu growth and persistence. Data on crop and pasture production will be used to compare the economics and trade-offs between crop and livestock components of mixed crop-livestock farms.

Conclusions

A survey of nine key farmers, agronomists and research personnel has captured the reasons for cropping kikuyu pastures, the different ways that the kikuyu is cropped and the agronomy of the system. It has also highlighted the gaps in knowledge which the EverCrop project hopes to fill over the next two years.

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Metabolites and biological entities in Victorian dairy farm soils and their relationships to management

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Abstract
Up to 60% of phosphorus (P) in soil is organic. Because plants generally access organic P *via* biochemical transformation to orthophosphate (inorganic P) (Marschner et al., 2011), understanding how organic P is converted to inorganic P may ultimately allow for reductions in orthophosphate fertiliser use. Three analytical techniques to better understand organic P processes were applied to dairy farm soils from treatments within P × K fertiliser trials at three sites in Victoria, Australia: the Northern Irrigation Region (NIR), south-western Victoria (SW Vic), and Gippsland. Analyses included: (i) physicochemical to measure total and available N, P and K, and pH, etc.; (ii) microbial community analyses to determine what microbes are in the soil and what is their function; and (iii) metabolomics to study the metabolites that microbes, plants and animals produce and use within the soil. Physicochemically, the sites were found to be significantly different ($P < 0.05$) for most soil analytical measures. P and K fertiliser applications increased available P and K. About 15 µg DNA/g soil was extracted from the Gippsland and SW Vic soils, compared to only ~9 µg DNA/g from the NIR soil. Archaea sequences (9.7 million) were more readily identified from the soil samples versus bacterial or fungi sequences (3.5 and 3.0 million respectively). Metabolomic analyses found approximately 1800 potential metabolites. Sixty metabolites, from a target list of ~200 compounds were identified including 24 amino acids, 16 sugars (including *myo*-inositol) and 6 organic P compounds. Cluster analyses of bacterial, archaeal and metabolomic data differentiated the sites. While the microbes and metabolites were closely related in concentration and identity at the NIR and SW Vic sites, the Gippsland soils were clustered due to differences in fertiliser treatments.

Keywords
Dairy soils, organic compounds, microbes, phosphorus

Introduction

Soils are a complex matrix of interacting geochemical (e.g. clays, water) and biological (e.g. microbes, plants) entities which affect how any metabolite is formed, transformed and transferred through the matrix (Daniel, 2005). Geochemical interactions occur within the soil due to soil pH, temperature and texture, among others (Kröger et al., 2013; Bronick and Lal, 2005). Biological interactions by microbes, plants, fungi and animals (e.g. earthworms) are the cause of many biochemical transformations of chemical compounds such as sugars (Gougoulias et al., 2014)), organic (Vance, 2001) and inorganic N (Masclaux-Daubresse et al., 2010), and phosphorus (P) (Nash et al., 2014). A greater understanding of these transformations may help to find ways to improve pasture quality and/or quantity (Pereira e Silva et al., 2013) by developing methods to access nutrients locked up in the soil matrix (Stutter et al., 2012).

As Australia's third largest rural industry, dairy is a significant contributor to the Australian economy (Dairy Australia, 2015a). Victoria has approximately 68% of Australia's dairy farms (Dairy Australia, 2015b), and there is an interest to improving the productivity of dairy farms through an understanding of the plant and soil interactions (Gourley et al., 2015). In particular, interest in how plants utilise N, P and other trace elements such as K, is ongoing.

This research is part of a larger project into the effects of P and K fertiliser on pasture production on dairy farms in the three largest dairy regions in Victoria. P is an important nutrient in plants, and its continued application to originally P deficient Australian soils, has resulted in relatively large pools of organic

P in dairy soils (Nash et al., 2014). By combining traditional agricultural analyses (e.g. Olsen P) with metabolomics techniques (the study of metabolites) and microbial community analyses, we are investigating the biochemical transformations occurring at the molecular and microbial scale. The research project focuses on organic P, although other metabolites were also investigated so as to understand the transformations occurring in the soil matrix.

Methods

Location

The three main dairy areas of Victoria are in Gippsland, Northern Irrigation District (NIR) and South West Victoria (Figure 1). The present study was based on a subset of treatments within three P × K trials (Table 1) established for the Sustaining Productive Dairy Soils (SPDS) project (Aarons, unpublished data).

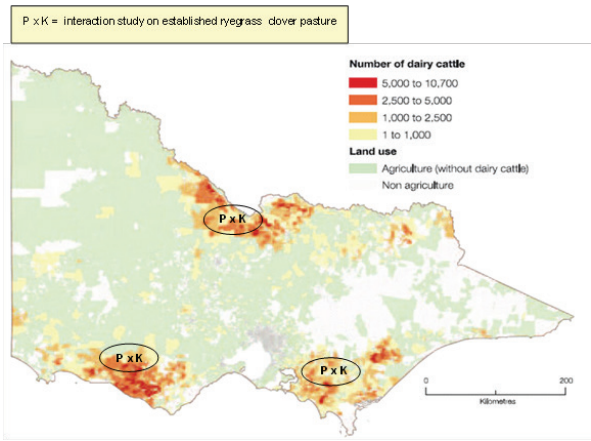

Figure 1. The location of the main dairy regions in Victoria, Australia where the three SPDS P × K trials are located.

Table 1. P and K fertiliser treatments in the SPDS trials, expressed as relative rates (cf. agronomic maintenance rate) of fertiliser applied per year. The 0× and 2× P maintenance rate treatments were sampled to maximize chance of discerning a P fertiliser effect.

		P maintenance rates				
		0	**0.25**	**0.5**	**1**	**2**
K maintenance rates	**0**	2	*1*	*2*	*1*	2
	0.25	1	*1*	*1*	*1*	1
	0.5	2	*1*	*2*	*1*	2
	1	1	*1*	*1*	*1*	1
	2	2	*1*	*2*	*1*	2

Sample collection

Soil samples (0-10 cm depth, c. 500 g composited from c. 40 individual cores) were collected from treatment plots in September 2014. Samples were immediately placed on ice and transported to the laboratory. Subsamples for metabolomics and soil community analyses were kept at -80C. Subsamples for physicochemical analyses were dried at 40C.

Analyses

Physicochemical analyses included pH, EC, Total P, Available P, Total C, Total N, Extractable S, ammonium (NH_4-N), nitrate, and exchangeable cations using standard methods. Metabolomic analyses used liquid-chromatography mass spectrometry (LC-MS) to search for all metabolites extracted with 80% acetonitrile. Data identifying retention time, mass/charge and concentration were collected in an untargeted manner. This data set was interrogated with a target list of compounds examined in-house and via the Maven database (Clasquin et al., 2002). Total community microbial DNA was extracted from the samples and analysed using microbial community sequencing. Taxomic libraries were created by targeting DNA sequences specific to bacterial, fungal and archaeal communities. Sequences obtained from the samples were clustered into operational taxomic units (OTU) and the identity of microbe OTUs was determined using the Ribosomal Database Project (Cole et al., 2014).

Results and Discussion

Physicochemical analyses

All physicochemical analyses showed significant differences between the farms ($P < 0.05$). For example, average Olsen P for the Gippsland (34 mg/kg) and SW Vic (29 mg/kg) samples was almost double that of NIR (17 mg/kg) samples (Table 2). Total P was more equivocal, with NIR having an average 412 mg/kg while for SW Vic and NIR it was 383 and 323 mg/kg, respectively.

Regardless of site, increasing P from 0× to 2× P fertiliser maintenance treatments increased Olsen and Colwell P ($P < 0.05$), and Total P by up to 55 mg/kg ($P = 0.053$). Addition of K fertilizer to plots reduced analyte concentrations between 2 and 10 fold. These effects were strongest for P (0.01 M $CaCl_2$) and Ammonium for SW Vic and NIR plots, while Gippsland plots to K were more varied but smaller. However, significant effects between K maintenance levels were only found for soil K, increasing from an average of 0.27 to 0.38 meq/100 g for plots with 2 × K.

Table 2. Selected P physicochemical measurements of the sampled sites.

		Olsen P (mg/kg)		Colwell P (mg/kg)		Colwell P Digest (mg/kg)		Total P (mg/kg)	
P level		0	2	0	2	0	2	0	2
Gippsland	Min	17	23	28	37	110	110	260	300
	Max	44	67	88	160	170	230	520	650
NIR	Min	10	19	23	45	50	76	360	380
	Max	18	28	41	68	82	110	440	460
SW Vic	Min	19	32	47	77	120	170	190	110
	Max	28	43	68	100	160	200	370	470

*Phosphorus fertiliser maintenance level applied annually.

Metabolomic analyses

Approximately 1800 untargeted features (metabolites and their adducts) were found using the untargeted metabolomics analyses. Using multivariate analytical techniques such as principle component analyses (PCA), it was found that the metabolites clustered into the three dairy regions studied (Figure 2). For SW Vic and NIR, metabolites clustered more tightly than those from Gippsland samples. 60 metabolites were identified including 24 amino acids, 16 sugars, 6 organic P compounds and 3 nucleotides. Of note, myo-inositol, the backbone of the largest organic component in soil, phytate, was identified. On average, amino acids were an order of magnitude more abundant cf. sugars while nucleotides and organic P compounds were an order of magnitude less. NIR and SW Vic samples only had 76% and 58% of the amino acid and nucleotide content of the Gippsland samples, respectively.

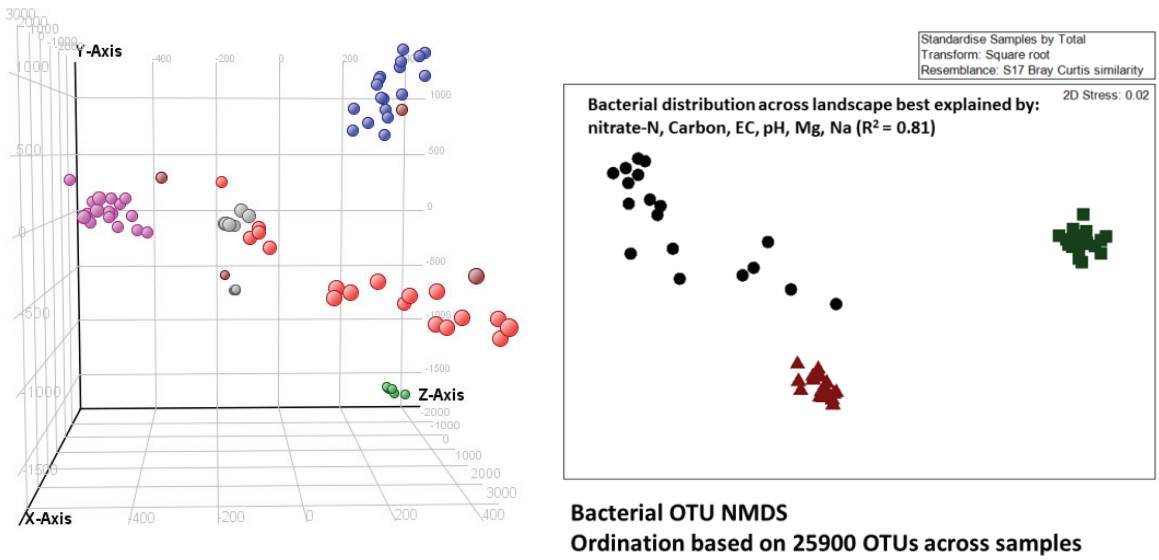

Figure 2. Left: PCA of untargeted data of metabolites found in soil samples from dairy farms in Gippsland (red), NIR (blue) and SW Vic (pink). Pooled Biological Quality Controls (grey); test of samples with no processing (brown); and target standards at higher concentrations (green) also shown. Right: Non-metric multidimensional scaling (NMDS) of bacterial operational taxonomic units (OTUs) taken from samples from Gippsland (circle), NIR (square) and SW Vic (triangle) sites.

Soil microbial community analyses

Similarly to the metabolomics analyses, soil microbial community data for bacteria and archaea were clustered by location, but the treatments for the Gippsland samples lead to a more varied concentration and

type of microbe compared with the NIR and SW Vic farms (Figure 2). This similarity of clustering using two different techniques suggests, for Gippsland soils at least, that the metabolomic and soil biology data are linked, as in the metabolites are predominantly sourced from microbes rather than the metabolites being from pasture plants, cows or soil geochemistry. For bacteria, more than 80% of the clustering was attributed to effects of soil pH, and nitrate, carbon, magnesium and sodium concentrations. Clustering of archaea OTUs was attributed to the same factors (R^2 = 89%). Fungal OTUs showed overlap of SW Vic and Gippsland samples, with a separation between those and NIR samples (R^2 = 66%). Across all sites, the largest groups of microbes identified included proteobacteria, acidobacteria, actinobacteria and bacteroidetes.

Conclusion

The soils from each site were physicochemically, microbially and metabolically very different. PCA and NMDS of the metabolomic and microbial data shows a similar pattern of a gradient of metabolites and microbes concentrations across the Gippsland site, while within each NIR and SW Vic site, metabolites and microbes varied little, regardless of N, P or K treatment. Further analyses is being undertaken to identify the linkages that lead to similar results for different targets and the methods used to identify them. For instance, fungi of the order Glomerales significantly increased (P = 0.026) if plots had been fertilised (vs. control plots). Similarly, seven metabolites were found to significantly vary in concentration depending on the rate of K fertiliser application. These metabolites included those involved in polysaccharide formation (D-glucuronolactone), vitamin transformations (D-Galactono-1,4-lactone, 4-aminobutanoate and aspartic acid) or related to other sugars found in plants. This research highlights how different advanced analytical techniques such as metabolomics and microbial community analyses may reveal how and why soil processes are occurring.

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Phosphorus requirements for cereals: what role does crop rotation play?

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Abstract
Cereals are the main broadacre crops grown in Australia. When grown in rotation with other crops, phosphorus (P) requirements for cereals may be impacted by the previous crop, similar to being impacted by Colwell P values. Current literature suggests different P requirements for wheat following cereals compared with wheat following canola. This study investigated P requirements in different cereal rotations using more than 100 field trials. The data contained recent field research data supplied by CSBP and Incitec Pivot (IPF), as well as trial data obtained from the "Making Better Fertiliser Decisions for Cropping System in Australia" (BFDC) project. Unlike lupins, cereals crops or pasture, which fitted along the same Colwell P - yield response curve, canola increased the critical Colwell P value for near maximum cereal production, especially on PBI_{+ColP} soils > 70. Cereal yields after canola tended to linearly decrease with higher PBI_{+ColP} and organic carbon (OC). Principal component analysis confirmed this trend, indicating PBI_{+ColP} and/or OC, being a measure for the capacity to immobilise P in the soil, is equally important as Colwell P, which is thought to represent the plant available P. Soil pH_{CaCl2}, texture and gravel was found to be of lower importance. Thus, critical soil test values for Colwell P can be refined on the basis of the interaction between previous crop and $PBI_{+Col}P$ or OC to account for higher P requirements in cereals after a canola crop, but multifactorial crop modelling may be preferred to further improve P recommendation in decision support tools.

Key words
P cycling, soil testing, cereal P requirements, crop sequence

Introduction
P recommendations for cereals based on Colwell P alone are sometimes poorly correlated to yield responses (Mason et al., 2010). Using such weak correlations may lower farm profits and affect confidence in soil testing. Thus, the BFDC project developed an interface that allowed users to filter P responsive field trials by various factors (Watmuff et al., 2013) to improve soil P – yield response correlations. Insufficient data exists to filter by phosphorus buffer index (PBI) or gravel content, factors which have been suggested by Bell et al. (2013) as likely to improve the soil P – yield response relationship. Crop rotation may be another factor interacting with the pools of plant available and sorbed soil P, commonly measured as Colwell P and PBI. Interrogation of the national BFDC database gave a critical Colwell P (95% max yield) of 34 mg/kg with a range of 29 – 40 (r = 0.47) for wheat trials where a cereal was the previous crop. Wheat following canola had a higher critical Colwell P of 49 (range 17-140) while wheat following a pulse had a lower critical Colwell P of 30 (range 17-53). These were smaller data sets and with weaker correlations of 0.24 and 0.35 respectively. This paper fills the gap of filtering by PBI for different crop rotations in regards to P requirements of cereals and focuses on soil test interpretation for profitable P management. As such it is related to: a) improving P soil tests; b) correlating / modelling the Colwell P – yield response curve in combination with other factors, like soil type, pH or crop sequence; and c) investigating the dynamics of P cycling in different crop rotations. Applying a better understanding of interactions between PBI, Colwell P and crop rotation may improve P management on farms and also benchmark studies on soil P status.

Materials and methods
The dataset contained 53 CSBP cereal field trials conducted in WA from 2000 – 2014 with maximum yields from 1.5-6.5 t/ha. Trials were on gravelly and non-gravelly soils, ranging from sand to clay. BFDC provided 43 trials (18 from SA, 17 from WA and 8 from NSW). IPF made 6 trials available from VIC / NSW. A conversion from the reactive iron and PRI test into PBI_{+ColP} has been applied for soil tests before 2008 using Watmuff et al (2013) and Weaver and Wong (2011). Mitscherlich equations have been fitted and regression correlation coefficients been calculated. Genstat (VSN International 2012) was used to perform a principal component analysis (PCA) on the CSBP dataset to investigate the metadata. A PBI map from WA using

52 000 soil samples (0-10cm) from the last 3 years, overlayed with a hot spot analysis, is given as further background to the relevance of this research in WA.

Results

Field trials showed a trend towards higher critical Colwell P for cereals on canola, especially on higher P sorption soils (Fig. 1a). Cereal on canola formed a different cluster to the other rotations on soils with a PBI_{+ColP} > 70 and improved soil test-relative yield relationships (Fig. 1a-d) when fitted separately. Regression correlation coefficients (r) for previous crops were: 0.03 (canola; PBI_{+ColP} < 70), 0.50 (canola; PBI_{+ColP} > 70), 0.16 (cereals), 0.58 (pasture) and 0.76 (lupins). Integrating subsoil Colwell P (10-20cm) did not improve soil P-yield correlations.

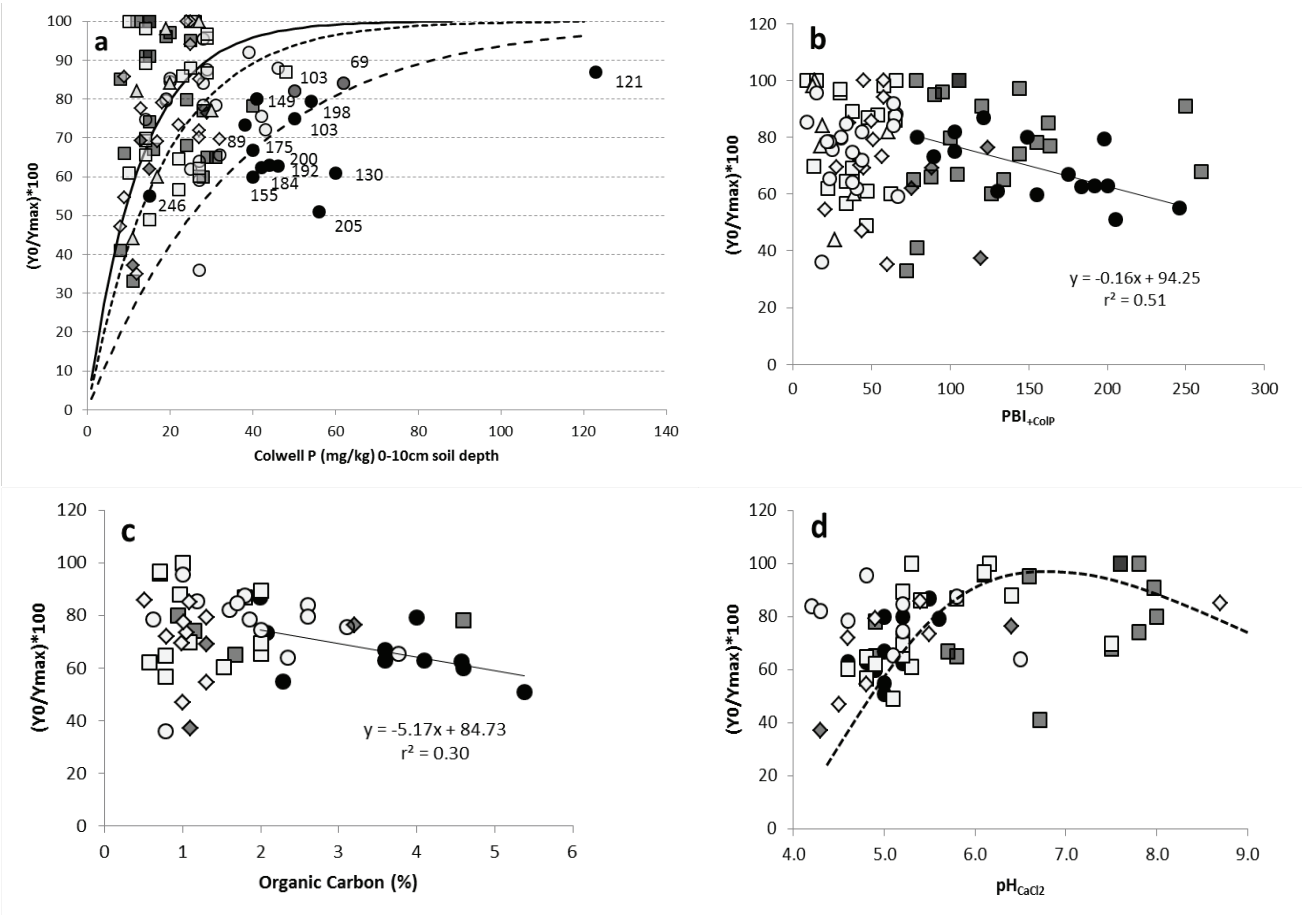

Figure 1a-d: Graphs show relative yield in response to Colwell P (a), PBI_{+ColP} (b), OC (c) and pH_{CaCl2} (d). Darker and lighter filled symbols show cereal trials on soils above and below PBI_{+ColP} 70 respectively. High PBI_{+ColP} values are inserted for cereals on canola (a). Fitted calibration curves (a) for the outer and middle one belong to cereal trials on canola (○) (dashed line for PBI_{+ColP} > 70; dotted line for PBI_{+ColP} < 70) while the inner one is for all other trial data (solid line). Symbols represent the previous crop as cereals (□), pasture (◊) and lupins (Δ). b-d: Only linear trend lines with equations are for cereals on canola on soils with PBI_{+ColP} > 70.

Correlations between Colwell P and yield were weak, highlighting risks with decision making based on this factor alone. Other factors were at least as important as Colwell P. Results from the first PCA loading weights, which explained 94% of the yield data, indicated in order of importance from highest to lowest: OC > PBI_{+ColP} > Colwell P > Gravel content > pH_{CaCl2} > Previous Crop > Soil texture .

Discussion

Colwell P has traditionally been regarded as the most important variable for P responses. This study found OC and PBI_{+ColP} of at least equal importance when generating P recommendations, in particular for a canola-cereal rotation. Canola removes similar P (kg/ha) in grain as cereals, considering twice the yield potential of a cereal crop, but leaves higher residual P in their biomass. Inorganic and organic forms of P in canola could account for a large percentage of the initial P supply during plant establishment. It becomes available

to the next crop (Noack et al., 2012), depending on mineralisation and soil P sorption capacity. Doolette et al (2012) observed higher P mobilisation and availability after lupins, but not canola. Both are non-hosts for arbuscular mycorrhizal fungi (AMF). Soil type, a possible surrogate for PBI, was found to be an important factor for plant available P. The higher P availability after lupins agree with pot studies (Nuruzzaman et al., 2005). Recently, higher P uptake in wheat on canola than in wheat on wheat has been reported (Lush, 2014). Even greater P uptake was reported for wheat on legumes. It has been hypothesised that this is caused by a healthier root system and increased root length as a result of improved N availability after the break crops. Our study cautions against relying on higher P availability after break crops. Based on trial data presented here we speculate that after canola a higher proportion of the mineralised P is to a lesser extent plant available on higher PBI_{+ColP} soils. While the P cycle under contrasting PBI's is not investigated here, the data clearly suggest applying above maintenance P rates after canola on higher PBI soils to reduce the risk of under-fertilising if no soil samples are taken for Colwell P.

Critical Colwell P values of this study only partly match outcomes of the BFDC project, which reports 34 mg/kg for cereals on cereals and 49 mg/kg for cereals on canola. Those values seem to hold only for PBI_{+ColP} soils < 70. The critical Colwell P for 95% maximum cereal yield on PBI_{+ColP} soils > 70 was about 110. Cereals following lupins fitted the same yield curve as cereals following pasture or cereals. Interestingly a higher PBI_{+ColP} did not necessarily result in a higher critical Colwell P, but instead depended on crop rotation. Unlike the strong Colwell P-wheat yield relationship in a study by Anderson et al (2013), this study showed an overall weak correlation of the Colwell P-yield response curve. A better fit when sorting by P sorption, was also observed in cases of weak correlations by Reuter et al (1995), but they did not consider crop rotation. Holford and Cullis (1985) found a strong influence of P sorption on moderately and highly buffered soils, similar to this study for cereals on canola. They demonstrated a superiority of the lactate over other soils tests like Colwell P. Colwell P was found to be more sensitive to buffer capacity and dry conditions than other soil tests. Furthermore, Mason et al (2013) and Doolette et al (2012) suggested DGT-P to be a more sensitive test than Colwell P to detect plant available P. While there may have been some limitations of the Colwell P tests in this study, fertiliser recommendation systems like the NUlogic® program for CSBP overcome some of those disadvantages by modelling complex relationships with i.e. PBI_{+ColP}, previous crop, gravel, pH_{CaCl2}, nutrient interactions of N, P and K, target yield and economic parameters.

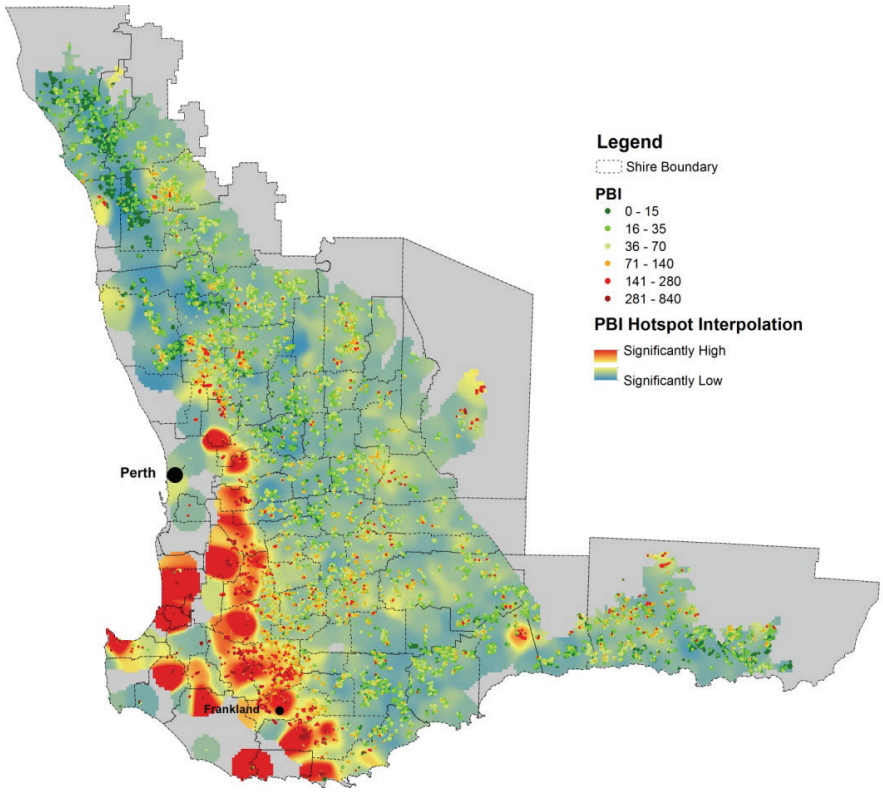

Figure 2: The PBI map of WA, grouped according to the national PBI categories, highlights locations of soils with PBI's above 70. These are marked in orange (10% of total samples) and red colours (5% of total samples) and can be described as mainly gravelly forest soils.

Crop rotation is not measured in a soil test, but it does affect the soil test interpretation for fertiliser recommendations. Multifactorial crop modelling is best suited to improve P recommendations, especially for areas with gravelly forest soils in WA (Fig. 2) and in the south eastern states (NSW, Vic, SA and Tas) where 40 and 8% of cropping soil tests fall into the category represented by orange and red respectively in Fig. 2 (based on samples submitted to Nutrient Advantage Lab Services). P deficiencies have been reported after canola even when fertilised according to critical soil test levels (Bowden et al., 1999). Different P distributions, positional availability problems, lack of AMF and root pruning after canola have been suggested as contributing factors to reduced P availability under higher PBI scenarios. While the influence of AMF, for which canola is a non-host, is likely to be negligible (Ryan and Kirkegaard, 2012), more factors may affect P availability, i.e. P placement, P source and cereal cultivars that differ in P-use efficiency (Bell et al., 2013). Further confounding factors can be early periods of dry growing conditions, water repellent soil or a compacted soil layer in the profile. Despite all the complexities, this study refines critical Colwell P values, improves DSS for P recommendations and could improve survey or benchmark reports for soil P status.

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Mycorrhizal status in the rotation: the importance to subsequent cotton establishment

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Abstract
Early vigor in cotton is related to its ability to access nutrients present in the soil. Mycorrhizal associations are known to benefit cotton establishment by enhancing nutrient and moisture acquisition, particularly phosphorus and zinc. If the colonisation of arbuscular mycorrhizal fungi (AMF) is incomplete, the cotton crop may be restricted in its establishment and growth. The need for vigorous germination, strong emergence and establishment at appropriate densities becomes paramount to subsequent crop development and ultimate yield. Commercial mycorrhizal testing of 'pre-plant' soil samples showed a wide range of spore counts (4-100 spores/g), dependant on the crop rotational circumstances. Additionally, a field site previously used for rice that displayed growth differences between old bank lines and the adjacent rice bay area was utilised for soil sampling. Paired soil core samples from these areas were taken in PVC tubes (100mm diameter, 250mm depth). Plant height and establishment rates were measured in the field at time of sampling. Plant heights at time of soil core sampling between bank and bay areas were significantly different (p <0.001). Subsequently, PVC tubes were then sown with cotton and utilised in a pot experiment. Cotton plants were grown for six weeks in a temperature controlled glasshouse (day/night cycle 30°C/20°C). Roots were then washed, stained and mycorrhizal colonisation was determined in each sample. Mycorrhizal colonisation was greater in soil cores sampled from old bank areas compared with the adjacent bay ($p < 0.05$).

This paper discusses the relationship between crop rotations and their effect on colonisation of mycorrhiza in cotton and the implications of converting old rice bays into raised beds for cotton production.

Key words
Crop rotations, cotton emergence, soil biology

Introduction

Cotton is one of the leading plant fibre crops worldwide and is grown commercially in the temperate and tropical regions of more than 50 countries (Smith 1999). In Australia, the bulk of the cotton industry is concentrated in northern New South Wales and southern Queensland. However the industry has made steady inroads to expanding the southern NSW area planted. Cotton is now grown commercially from the Victorian border to Emerald in central Queensland, and as far west as Bourke and Lake Tandou in New South Wales. Cotton is grown either as a dryland crop, relying on rainfall, or as an irrigated crop where a reliable water supply is available. The total area planted to cotton in Australia was about 583,000 hectares in 2011/12 season. Cotton in southern regions is grown in rotation with rice and winter crops, thus experiences a different set of agronomic challenges specific to the south. The shorter season associated with southern cotton production necessitates strong germination, emergence and establishment as there is little time for compensatory growth resulting in lowered yields. The switch in crop from rice to cotton also presents unique growth and development problems to cotton in southern Australia, which are not yet elucidated.

As mycorrhizal associations are known to benefit cotton establishment, determining their colonisation subsequent to rice in the rotation was investigated. Mycorrhiza are ubiquitous plant symbionts which colonise the root systems of most terrestrial plants (Nehl *et al*. 1996). The fungus relies on the plant to provide carbohydrates and in exchange provides the plant with an underground hyphal network that extends the root system and allows increased uptake of nutrients and moisture (Ho and Trappe 1973). The predominant type of mycorrhiza found associated with 60-70% of plant species are arbuscular mycorrhizal fungi (AMF) and these are associated with the roots of cotton.

The two objectives of this study were-

1. To measure the AMF content in soil to determine the level and variability of colonisation following different crop rotations in the southern NSW region.
2. Investigate mycorrhizal colonisation in soil cores taken from an area which exhibited poor cotton growth after rice bay conversion to raised beds.

Method

Pre-plant field collection

Field soil and cotton roots for pre-plant testing and in crop testing were collected from two farms in the Coleambally and Darlington Point areas. Pre-plant soil was sampled according to Forecasta pre-plant® requirements and commercially tested by Microbiology Laboratories Australia. Briefly, supplied containers were filled with field collected soil and sampled at a rate of one sub sample per hectare using a diagonal transect through each cotton field. Each sample was bulked into the final sample and subsequently sealed and immediately sent for commercial testing.

Glasshouse experiment

Paired soil cores utilised in the pot experiment were taken from a cotton field in the Coleambally irrigation area where the old bank lines were and adjacent rice bay areas were apparent. Core samples were taken in PVC tubes (100mm diameter, 250mm depth). Subsequently, the PVC tubes were sown with cotton as a pot experiment. Cotton plants were grown for four, five and six weeks in a temperature controlled glasshouse (day/night cycle 30°C/20°C) before being sampled. Soil cores were held in individual plastic bags and placed in a large watertight container and each bag filled with a 2g L^{-1} sodium hexametaphosphate solution and allowed to soak for one hour to facilitate the separation of roots and soil. Soil was then transferred to a bucket and agitated vigorously with a jet of water. After allowing the sample to settle for several seconds, the supernatant was poured onto a fine sieve (250µm). Roots were then recovered and stored in 70% ethanol until the staining process was performed. The staining method is adapted from Koske and Gemma (1989). Briefly, 0.3-0.5g fresh roots were transferred to custom staining tubes and submerged in 10% KOH and placed in a 90° C water bath for one hour. Roots were subsequently acidified with 2% HCL for 5 minutes before the staining solution (acidified glycerol, water and 0.05% trypan blue) was added and placed back in a 90° C water bath for 20 minutes. Stained roots were then de-stained for 30 minutes in a 90° C water bath with acidic glycerol to remove excess stain. Colonisation of cotton roots (as percent of root length infected) were then assessed using the line intersect method described by Giovannetti and Mosse (1980).

Experimental design and statistical analysis

Paired soil cores were arranged in a randomised block design with three sampling times.
Effects of sampling time and location in the field (bank or bay) were tested using a two way analysis of variance. For the field measurements, the effect of location in the field was tested using a one way analysis of variance. Correlation between shoot dry matter and mycorrhizal colonisation was tested using a Pearson product moment correlation. All statistical analyses were performed in R statistical package (R Development Core Team 2008*)*.

Results and discussion

Pre-plant field collection

Canola crops had the lowest mycorrhizal spore and colonisation levels followed by rice (Table 1). Canola does not associate with mycorrhizal fungi. Canola crops are known to produce a biofumigation effect on the soil with toxic chemicals such as glucosinolates and their breakdown products isothiocyanates likely to be responsible for decreased mycorrhiza in the soil (Glenn *et al*. 1988; Vierheilig *et al*. 2000). Variation in spore counts are likely to have been affected by different management practices between between sampling locations.

Table 1 Results from commercial (VAMwise) 'Forecasta pre-plant' tests of soil collected from cotton fields in 2014/15 season for mycorrhizal spore content (spores/g) and predicted colonisation percentage.

2013/14 crop	Spore count (spores g^{-1})	Colonisation (%)
Canola	4	12.8
Canola	5	16
Canola	6	19.2
Canola	7	22.4
Canola	9	28.8
Canola	13	41.6
Rice	20	64
Fallow	35	100
Wheat	40	100
Cotton	51	100
Cotton	70	100

Glasshouse experiment

At the time of soil core sampling plant heights were significantly different (p <0.001; Table 2), Bank areas sampled exhibited higher growth as compared with old rice bay areas. There was a clear effect seen in the field at the time of sampling and the old bank line was easily distinguished from the adjacent bay. However there was no effect on establishment rate per metre of row (Table 2) or the mean number of nodes found per plant per metre row when the soil cores were taken.

There was a significant main effect between combined sampling time means of bank and bay shoot matter (p <0.05). There were also differences in mycorrhizal colonisation (p <0.05) between combined means of bank and bay soil cores. Mycorrhiza have been reported to always be associated with the roots of cotton and found to increase the growth and development of cotton plants, as well as cause earlier flowering and boll formation (Rich and Bird, 1974; Price *et al*. 1989; Nehl *et al*. 1996). There was a strong positive correlation between combined sampling time means of shoot dry matter and AMF colonisation (Pearson correlation coefficient =0.781; $p \leq 0.01$).

Table 2 Mean observations comparing old bank lines and the adjacent rice bay area

Observations	Bank	Bay	
In-crop heights (mm)	733	499	$p < 0.001$
Establishment (plants m^{-1})	12.2	13.1	NS
Nodes (nodes $plant^{-1}$ m^{-1})	13	11	NS
Colonisation (%)	43.88	21.80	$p < 0.05$
Shoot dry matter (g $plant^{-1}$)	0.460	0.374	$p < 0.05$

Where rice has been the prior crop, rice bay area's had a lower mycorrhizal colonisation rate compared with bank areas. The inundation of rice crops changes the soil biology and chemistry, previous research having shown that phosphorus and zinc are immobilised in the soil post-rice (Willet *et al*. 1978) leading to slower early growth.

Conclusions

AMF spores were lower in soil of cotton fields that had previously canola. This may be due to the biofumigation effect canola produces. The lower spore counts found in cotton fields previously sown with rice are likely due to the inundation of the soil whereby the anaerobic conditions may have inhibited mycorrhizal spore production. AMF are essential for normal cotton growth and yield. If the number of AMF propugales in the soil is low, colonisation of the roots is delayed and plant growth may be depressed, with subsequent delays in maturity and reductions in yield. The importance of mycorrhizal associations in southern NSW, and their potential for enhancing cotton establishment, require further investigation.

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Identification of the critical factors of System of Rice Intensification (SRI) for maximizing Boro rice yield in Bangladesh

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Abstract
Field experiments were conducted at the Bangladesh Rice Research Institute (BRRI) research farm, Gazipur, during 2007-2011 with a view to investigate the effects of the critical factors of SRI on the yield performance of irrigated *Boro* rice cv. BRRI dhan29. The highest grain yield in the first round of trials (7.80 tha^{-1}) was obtained when the crop was transplanted on 30 November using 12-day-old seedlings followed by 15 December (7.71 tha^{-1}) under SRI. Earlier and later transplanting gave lower yield with SRI methods. Grain yields of 7.82 tha^{-1} and 7.90 tha^{-1} were achieved in 2008 and 2009, respectively, under SRI irrigation regime combined with three times weeding/soil stirring at 20, 35 and 45 days after transplanting (DAT). Higher grain yields (8.44 tha^{-1} in 2008 and 8.52 tha^{-1} in 2009) were recorded from the application of 10 tha^{-1} of cow dung manure + 100% of the recommended inorganic fertilizer (RF) together with three times weeding/soil stirring. The wider-spacing treatments of 30cm × 25cm and 30cm × 30cm in 2008 were found to be essentially the same, with grain yields of 8.45 tha^{-1} and 8.40 tha^{-1}, respectively, when used with 12-day-old seedlings raised from a compost bed nursery. It was observed that the best performing SRI treatment was with wider spacing (30cm × 25cm), SRI irrigation schedule, younger seedlings (12 days old) raised in a compost bed, with 3 times weeding/soil stirring, and 10 tha^{-1} of cow dung manure + 100% RF. These produced the highest grain yield (10.17 tha^{-1}), which was 93% higher than the yield of 5.27 tha^{-1} obtained at the same time from the treatments that used BRRI recommended practices.

Key words
Soil stirring, SRI irrigation, Seedling age, Time of planting, Spacing, Manure.

Introduction

Rice is cultivated in 10.37 million hectares of land in Bangladesh, and the production is about 25.15 million tons, with an average yield of 4.4 tha^{-1} (BBS, 2006; IRRI, 2015). This yield level is well below that of many other rice-growing countries such as China, Japan, Korea and Egypt with yields of 6.8, 6.7, 7.5 and 10.10 tha^{-1}, respectively (IRRI, 2015).

The System of Rice Intensification - in French, called le Système de Riziculture Intensive; referred to as SRI in English and French and as SICA in Spanish -- is quite literally a "system" rather than a "technology" because it is not a fixed set of practices. The specific practices recommended for SRI should always be tested and verified according to local conditions rather than simply adopted (Uphoff et al, 2002).

The basic elements of SRI are transplanting younger seedlings quickly, carefully and shallow; wide spacing between plants so that roots and canopy have more room to grow; water management which keeps the soil moist but not continuously flooded; control of weeds by a mechanical weeder which aerates the soil as well as buries weeds in the soil as green manure; and increased applications of manure, compost or other organic matter to improve soil structure as well as functioning. These practices together promote larger, healthier and long-lived root systems and more abundant communities of beneefficial soil organisms.

This new approach for increasing rice yield was first developed in Madagascar by Fr. Henri de Laulanié, S.J., who worked with Malagasy farmers during 1961 and 1995 to explore the possibilities of enhanced rice production in that country (Laulanié, 1993). SRI is not a fixed package, but rather a set of principles translated into modifications of common practice for raising the productivity of all of the factors involved in rice production: land, labour, capital, seed, and water.

The System of Rice Intensification (SRI) methodology has been reported to have a high production potential in the *Boro* season in comparison with currently recommended practices, farmer practices, the seedling-throwing method, and use of a drum seeder in the light textured soils of Bangladesh (Sarker *et al.*, 2007). However, systematic evaluations need to be undertaken to gain an understanding of the principles underlying the higher productivity of SRI methods and how they under specified agro-ecological conditions. This has not been done previously in Bangladesh. So, the results of a detailed, multi-year study of the respective factors in their possible combinations at a given environmental site like that of the BRRI at Gazipur are worth examining.

Materials and Methods

A total of nine field experiments were conducted at the BRRI experimental farm at Gazipur to find out what are the critical factors of System of Rice Intensification (SRI) and what are their values for maximizing Boro rice yield in Bangladesh. Experiments no. 1, 2, 3 and 4 were conducted during Boro 2007-08 (November through May) and these were repeated as experiments no. 5, 6, 7 and 8 during Boro 2008-09 to fulfill the objectives of the study. The location of the experimental site was between 23°59'23.03" N latitude and 90°24'19.38" E longitude, at a mean elevation of 49 ft above sea level. The site belongs to the agro-ecological region of Madhupur Tract. The mean annual precipitation is 2039 mm. The mean annual temperature is 25.7°C, with a mean maximum temperature of 30.4°C and a mean minimum temperature of 21.1°C. The day length ranges from 10.7 to 13.7 hours.

Description of the Experiments: Expts. 1 & 5 were aimed to investigate the effects of crop establishment time and of seedling age on crop performance of *Boro* rice under SRI management. Six planting times along with four seedling ages were evaluated. Expts. 2 & 6 aimed to investigate the effects of irrigation water management and of soil stirring on the performance of *Boro* rice. Six water managements along with four stirring treatments were evaluated. Expts. 3 & 7 were conducted to find out the effects of organic and inorganic fertilizers along with soil stirring on crop performance of Boro rice under SRI practices. Eight fertilizer and manure treatments along with three soil stirrings were tested. Expts.4 & 8 were planned to investigate the effects of spacing and seedling-raising method on the crop performance of Boro rice along with other SRI management practices. Six spacing treatments together with four seedling-raising methods were evaluated. In Experiment 9, a final comparison was made in Boro season 2010-11 whereby the best-performing SRI factors that hads emerged out of the previous 8 trials were tested against the BRRI-recommended *Boro* rice production system.

A total of 32 treatments under five factors were evaluated. ***Factor A: Two irrigations (I),*** I_1= BRRI recommended water management, i.e., 5-7 cm depth irrigation followed by further irrigations at 3 days after disappearance of water from the soil; this irrigation was continued up to PI stage, after which 5- 7 cm standing water was kept up to the hard dough stage; and I_2= SRI water management, 2-3 cm depth of water added during irrigation time just for soaking the soils, with further irrigation added 3 days after disappearance of water from the soil; this irrigation was continued up to panicle initiation (PI) stage, when 5-7 cm standing water wre maintained up to hard dough stage; this was selected for expts. 2 & 6. ***Factor B: Two manure and fertilizer treatments (N),*** N_1= manure @10 tha^{-1} + 50% of the recommended inorganic fertilizers; and N_2= manure @10 tha^{-1} + 100% of the recommended inorganic fertilizers (100% inorganic recommended fertilizer was 250-80-100-10 kgha^{-1} of N-P_2O_5-K_2O-S, respectively). ***Factor C: Two spacings (S),*** S_1= recommended spacing as per BRRI (20 x 20 cm); and S_2= best-performing spacing in SRI (30 x 25 cm). ***Factor D: Two seedling ages (A),*** A1= 40-day-old seedlings; and A2= 12-day-old seedlings. ***Factor E: Two weedingss/soil stirringss (M),*** M_1= no stirrings; and M_2= three stirrings, at 15, 35 and 45 DAT. The experiments were laid out in a split-split plot design with three replications and all the treatments were kept weed free by manualy.

Results

From Expts. 1 & 5, the best-performing transplanting time was found to be either 30 November or 15 December with 12-day-old seedlings (Fig. 1). Earlier and later plantings performed less well. Selected best-performing treatment of Expts. 2 & 6 was SRI water management with three stirrings at 15, 30 and 45 DAT (Fig. 2). The best-performing SRI treatment from Expts. 3 & 7 was 10 tha^{-1} of manure + 100% of the recommended inorganic fertilizer treatment interacting with three stirrings at 15, 30 and 45 DAT (Fig. 3). From Expts. 4 & 8 the selected best-performing treatment was wider spacing of 30 × 25 cm when 12-day-old seedlings was raised from the compost-bed method (Fig. 4).

In Experiment 9 in the 2010-11 *Boro* season, higher grain yield increase was observed when SRI practices relating to irrigation, weeding/soil stirring, spacing, and seedling age interacted, in comparison with the presently recommended practices (Table 1). It was observed that wider spacing (S_2), SRI irrigation method (I_2), younger seedling age (A_2), three soil stirrings (M_2), and 10 t ha^{-1} compost with recommended inorganic fertilizers (N_2) resulted in higher grain yield than the present recommendations for spacing (S_1), irrigation method (I_2), older seedlings (A_1), and no stirring (M_1).

The highest grain yield (10.17 t ha^{-1}) was obtained from the treatment $S_2A_2M_2I_2N_2$ where all selected best SRI principles were collectively interacting, followed by the treatment $S_2A_2M_2I_1N_2$ (9.43 t ha^{-1}) where also all the selected best SRI practices were performed together but irrigation management was different. Also it was better than the treatment $S_2A_1M_2I_2N_2$ (7.97 t ha^{-1}), where also all SRI practices except seedling age were performed together. It is also observed that nutrient management N_1, that is applying manure @ 10 t/ha + 50% of the recommended inorganic fertilizer treatment had always a significantly negative affect compared to nutrient management N_2, that is manure @ 10 t/ha + 100% of the recommended inorganic

fertilizer management treatment in respect of all the other tested factors combinations. This occurred due to less amount of nutrient which did not fulfill the plants' requirements and it also may have affected the soil's fertility status in terms of supportive biological activity.

Grain yield results showed that nutriment management had a highly significant interaction with spacing and seedling age. Higher grain yield was recorded when N_2 nutrient management treatment interacted with more of of the SRI factor treatments. It is observed that grain yield of BRRI dhan29 was significantly affected by nutrient management interactions with irrigation and stirring treatments. In all aspects of irrigation and stirring treatments, N_2 nutrient management produced higher grain yield than N_1 nutrient management.

Conclusions

Based on the study, it may be concluded that integration of the best-performing SRI cultural factors may be recommended for maximization of *Boro* rice yield for a long-duration variety like BRRI Dhan29 in Bangladesh. The following best-performing SRI cultural factors are to be considered: 1. Transplanting should be done during the period from 30 November to 15 December. 2. Younger seedlings of 12-days age, preferably raised in compost bed, should be used for transplanting. 3. Transplanting may be done with wider spacing of 30cm × 25 cm than at present. 4. SRI irrigation management should be followed. 5. Soil stirrings at 15, 30 and 45 DAT may enhance the productivity irrigated rice. 6. Only BRRI-recommended fertilizer applications are not enough for maximizing grain yield with SRI techniques. Integrated use of fertilizer and manure at 10 t ha^{-1} manure along with recommended rate of inorganic fertilizers would enhance the productivity.

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Table 1: Effect of selected factors of System of Rice Intensification (SRI) techniques in comparison with existing recommended practices on grain yield (tha^{-1}) of BRRI dhan29 in *Boro* season.

Sub Plot (Spacing × Seedling Age)	Main Plot (Irrigation × Stirring)	Sub-sub plot (Nutrient management)		
		N_1	N_2	Differences
	$A_1 = M_1I_1$			
$B_1 = S_1A_1$	M_1I_1	5.27 c	5.85 b	-0.58 *
$B_2 = S_1A_2$	M_1I_1	5.62 b	6.72 b	-0.81 *
$B_3 = S_2A_1$	M_1I_1	6.04 ab	6.74 b	-0.70 *
$B_4 = S_2A_2$	M_1I_1	6.65 a	7.39 a	-0.74 *
	$A_2 = M_1I_2$			
$B_1 = S_1A_1$	M_1I_2	6.00 b	6.57 c	-0.57 *
$B_2 = S_1A_2$	M_1I_2	6.28 b	6.93 bc	-0.65 *
$B_3 = S_2A_1$	M_1I_2	6.82 a	7.65 ab	-0. 83 *
$B_4 = S_2A_2$	M_1I_2	7.08 a	7.79 a	-0.71 *
	$A_3 = M_2I_1$			
$B_1 = S_1A_1$	M_2I_1	5.54 c	6.26 c	-0.72 *
$B_2 = S_1A_2$	M_2I_1	6.39 b	7.48 b	-1.08 **
$B_3 = S_2A_1$	M_2I_1	6.25 bc	7.83 b	-1.58 **
$B_4 = S_2A_2$	M_2I_1	7.72 a	9.43 a	-1.71 **
	$A_4 = M_2I_2$			
$B_1 = S_1A_1$	M_2I_2	5.87 c	6.62 c	-0. 75 *
$B_2 = S_1A_2$	M_2I_2	7.03 b	7.84 b	-0.81 *
$B_3 = S_2A_1$	M_2I_2	6.63 b	7.97 b	-1.35 **
$B_4 = S_2A_2$	M_2I_2	7.87 a	10.17 a	-2.30 **

** = significant at 1% level, * = significant at 5% level, ns = not significant

In a column under each A, means followed by a common letters are not significantly different at the 5% level by DMRT.

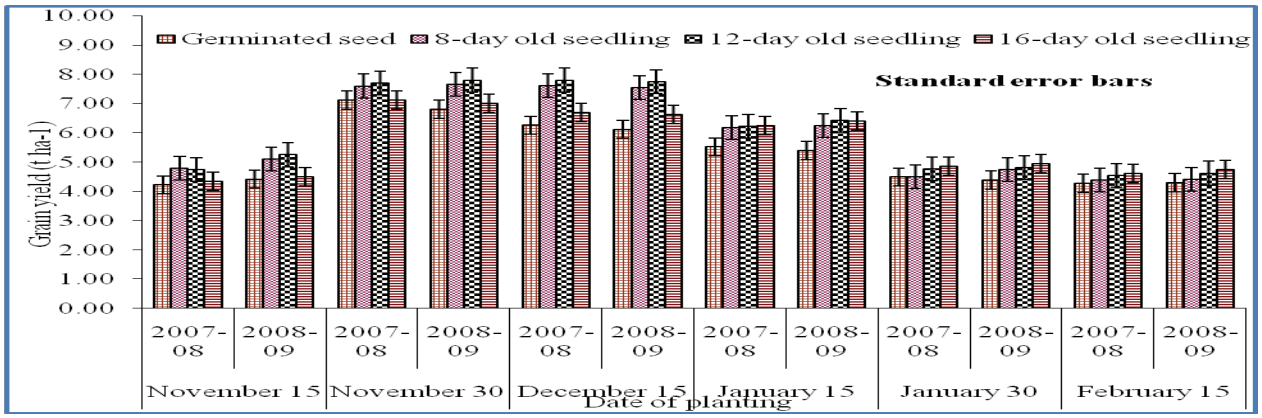

Fig. 1 Effect of date of planting and seedling ages on grain yield (t ha^{-1}) in expts. 1 & . 5 in *Boro* seasons under SRI techniques.

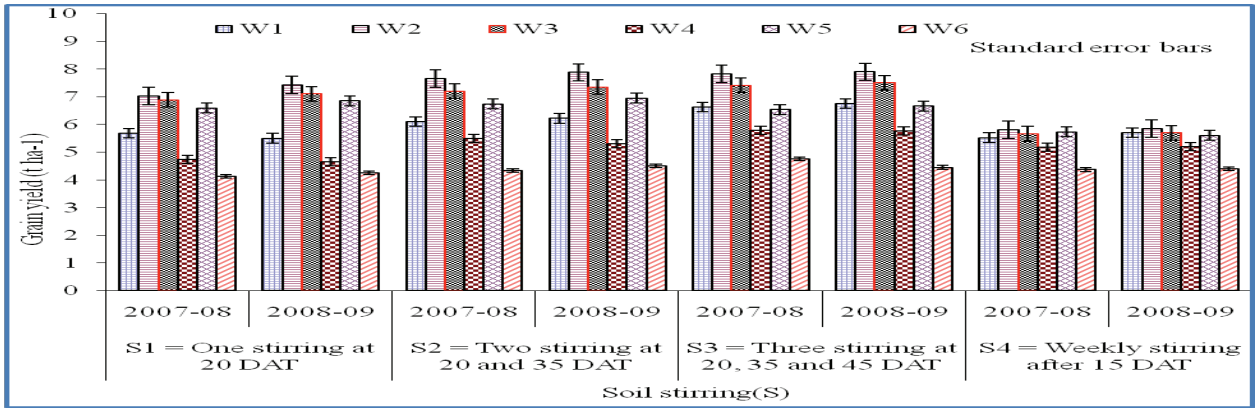

Fig. 2 Effect of SRI water management technique and soil stirring on the grain yield (t ha^{-1}) of BRRI Dhan29 in expts. 2 & 6 under SRI techniques.

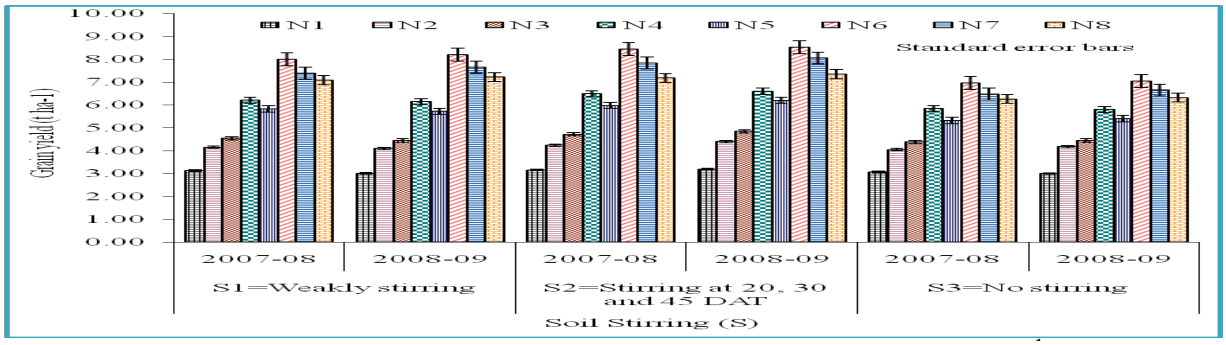

Fig. 3. Effect of integrated use of fertilizers and manures and soil stirring on the grain yield (tha^{-1}) of BRRI Dhan29 in Expt. 3 & Expt. 7 under SRI

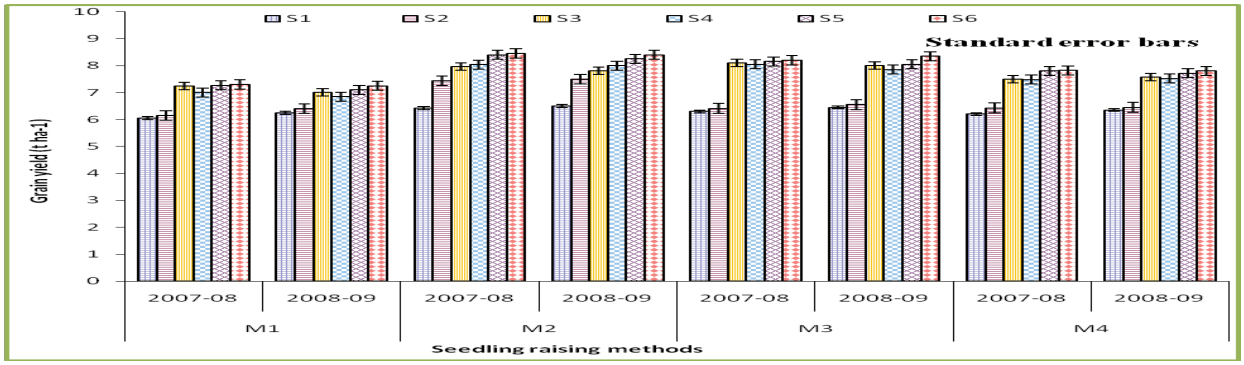

Fig. 4. Effect of spacing and seedling raising methods on the grain yield (t ha^{-1}) of BRRI Dhan29 in Expt. 4 & Expt. 8 under SRI

In situ acidulation of rock phosphate

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Abstract
The ability to utilize local rock phosphate (RP) deposits is often limited by the availability of the P they contain. Application of fine elemental S (ES) with ground rock phosphate is a potential way to alleviate this problem and to supply S to the plants. An experiment was conducted, using North Carolina rock phosphate, to examine the impact of incorporation of fine elemental S into the fertilizer granule. The application of a sulfate basal allowed the impact of P availability to be studied. There was an almost doubling in the yield in the first six weeks after application of rock phosphate + elemental S compared to rock phosphate alone which was attributable to the increased P availability (4.6% with RP, 10.3% with RP+ES) brought about by in situ acidulation of the rock phosphate. In the second six week period, where basal P was applied, the S in the fertilizer granule was shown to continue being oxidized. These rock phosphate/elemental S assemblages could prove very beneficial in remote areas and in developing countries where fertiliser production facilities are limited.

Key words
Phosphorus, sulfur, sulphur, fertilizer, fertiliser

Introduction
There are many rock phosphate deposits in developing countries which would be useful to local agriculture if there was a local facility to convert the slowly soluble octacalcium phosphate to plant available orthophosphate. One of the earliest reports on rock phosphate/elemental S fusions is that of Kittoe and Attoe (1965). Swaby (1975) found that the effectiveness of rock phosphate/elemental sulfur (S) assemblages (Biosupers) was dependent on the reactivity of the rock phosphate (RP), to a certain extent on the granule size, the P retention capacity of soil, the duration of cropping and soil moisture and temperature as they effect S oxidation. Freisen et al. (1987) showed that addition of elemental S to various rock phosphates resulted in acidulation of the rock over time.

One of the main factors which affects S oxidation rate and hence potential acidulation rate, is the particle size of the elemental S. Dry grinding of elemental S can be hazardous due to the explosivity of the fine dust. Recent advances in wet grinding technology (eg. US Patents 4372872A, US8679219 B2) have reduced this hazard and it is now feasible to safely prepare fine elemental S. As an alternative molten elemental S can potentially be added to crushed RP during granulation. The aim of the study reported here was to examine the impact on P availability from North Carolina rock phosphate resulting from the addition fine elemental S.

Materials and Methods
The study was undertaken in a glasshouse at the University of New England, Armidale, NSW, Australia. A Tenosol soil of granitic origin, known to be S deficient was collected from the Kirby Experimental Station of the University. The soil was collected from the 0-30 cm horizon, dried, ground, and passed through a 2.0 mm sieve. The total S concentration in the soil was 204 µg/g and KCl-40 S was 1.3 µg/g.

PVC plastic pots with an inside diameter of 15 cm and 12 cm depth were filled with 1.3 kg of soil and watered gradually over two weeks to leach out sulfate. The pots were allowed to stand until the soil was drained to field capacity. The solid fertilizer treatments shown in Table 1, along with a small amount of soil which previously received elemental S to act as an inoculum for *Thiomonas* (an elemental S oxidizing bacteria), were applied to the surface of this soil layer and an additional 200 g of soil and placed on top of the 1.3 kg soil. There were 4 treatments (Table 1) with three replicates. All treatments received P at a rate equivalent to 45 kg/ha either in the fertiliser or as an addition of DAP in the SSP and ES treatment. S was applied at 15 kg/ha (27 mg/pot) in the SSP and ES treatments based on pot surface area. Additional S was

applied as ammonium sulfate in the RP and RP+ES treatments to remove S nutritional effects so differences in P availability could be detected. N, P, K and Mg were applied to all treatments at rates of 80, 45, 40 and 10 kg/ha, respectively as Urea, DAP, KCl, and MgCl2. The rock phosphate used was from the North Carolina deposit which was ground to <250 mm and the elemental S had a particle size <75 mm. The RP and RP+ES fertilisers were granulated into 2-3 mm granules using calcium lignosulfonate as the binder and elemental S was added at the rate of 10.7%. The rock phosphate and RP+ elemental S treatments received 26 mg per pot of as ammonium sulfate S to remove any nutritional effects of S.

Table 1. Fertilisers used in the experiment

	Analysis				
Treatment	N	P	S	Sulfate	Elemental
Control (+P-S)					
Single superphosphate (SSP)	0	8.6	11	11	0
Rock phosphate (RP)	0	13	0	0	0
RP+ elemental S (RP+ES)	0	11	10.7	0	10.7

The pots were set up in the glasshouse and the soil maintained at field capacity for two weeks to initiate S oxidation before the first planting. Four 4-day old pre-germinated seeds of maize were sown in each pot to a depth of 2-2.5 cm. The pots were then watered to near field capacity within one week. After one week plants were thinned to two healthy plants per pot and the moisture content adjusted to field capacity and maintained with tap water for the majority of the experiment. Excess water was applied at intervals to leach out sulfate to simulate field conditions. The temperature of the glasshouse was maintained at 20-30°C throughout the first crop in the experiment which was grown for 5 weeks.

After this first crop the soil in the pots was allowed to air dry and the pots containing the soil were stored for 10 weeks before the second crop was planted. A the commencement of the second crop the pots were first watered to above field capacity and to leach out sulfate before being replanted with maize as in the first planting. P was applied at a rate equivalent to 45 kg/ha as diammonium phosphate to all treatments. This was done to remove P limitations to growth to see if S was still being oxidized in the RP+ elemental S treatment. The crop was grown for 6 weeks. Additional urea was applied throughout both trials to ensure that nitrogen deficiency did not limit plant growth.

Maize tops were harvested cutting plants 1.5 cm above the soil surface. The harvested tops were dried in an oven at 60°C until constant weight. The dry plant tops were weighted and ground to pass a 1 mm screen and analyzed using Ultrawave Microwave Digestion with nitric acid. Total P and S, as well as other macronutrients and micronutrients were measured by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). P and S recovery was determined from chemical analysis of the harvested tops.

Results and discussion

There was a substantial response to S, applied as sulfate, in the first crop (compare control and SSP treatments in Table 2). Although the same amount of P and S were applied to the SSP, RP and RP + ES treatments yields were significantly lower in the latter two treatments than in the SSP treatment indicating a lower availability of P in the RP treatment which was supported by P content data. The yield in the RP+ES treatment was significantly higher than in the RP treatment although the same amount of S had been applied to both treatments (basal ammonium sulfate applied) indicating that the elemental S in the RP+ES treatment increased P availability. This is supported by the P content data for these two treatments. Despite the same amount of S being applied in the SSP and RP treatments the highest S content was in the SSP treatment which was the result of the higher P availability in this treatment. The higher P and S contents in the RP+ES treatment compared to the RP alone treatment are the result of increased P availability in the RP+ES resulting from the acidulation of the RP from elemental S oxidation.

Table 2. Tops dry weight yield (g/pot) and tops P and S contents (mg/pot) of maize in crops 1 and 2.

Treatment	Tops DWt (g/pot)	P content (mg/pot)	S content (mg/pot)
		Crop 1	
Control (+P-S)	8.46 b[A]	26.9 b	4.9 c
Single superphosphate (SSP)	17.40 a	35.3 a	19.5 a
Rock phosphate (RP)	3.09 c	3.7 d	4.8 c
RP+ elemental S (RP+ES)	6.93 b	8.3 c	14.1 b
		Crop 2	
Control (+P-S)	2.71 b	26.2 c	2.1 b
Single superphosphate (SSP)	5.11 a	36.2 bc	5.8 b
Rock phosphate (RP)	4.69 a	43.4 a	4.0 b
RP+ elemental S (RP+ES)	5.57 a	39.5 ab	16.5 a

[A] Within a crop numbers in a column followed by the same letter are not significantly different according to DMRT

In the second crop the maize tops yield was significantly higher in the three fertiliser treatments than in the control (Table 2) indicating that the soil was S deficient. When P was applied to all treatments in the second crop there was no significant difference in yield between the three fertiliser treatments (Table 2) indicating that P and S availability was adequate for plant growth in each treatment. The highest S content was found in the RP+ES treatment which is the only treatment where ES had been applied. This suggests that the sulfate in the SSP and in the ammonium sulfate applied as a basal in the RP and RP+ES treatments had been leached.

In the first crop there was a higher percent P recovery in the SSP treatment than in the control despite both having the same P application rate presumably because a lack of S in the control limited yield. The apparent S recovery from SSP treatment was 56% (Table 3). The % P recovery in the RP and RP +ES treatments was significantly lower than from SSP. The % P recovery and apparent fertilizer S recovery was higher in the RP+ ES treatment compared to RP alone suggesting that the oxidation of elemental S in the fertilizer granules had increased the availability of P.

Table 3. P and S recovery in plant tops

Treatment	% P recovery	% Apparent fertiliser S recovery
	Crop 1	
Control (+P-S)	33.7 b[A]	
Single superphosphate (SSP)	44.2 a	56.0 a
Rock phosphate (RP)	4.6 d	0.0 c
RP+ elemental S (RP+ES)	10.3 c	8.9 b
	Crop 2	
Control (+P-S)	16.3 b	
Single superphosphate (SSP)	22.6 a	14.2 a
Rock phosphate (RP)	27.2 a	7.2 b
RP+ elemental S (RP+ES)	24.9 a	14.0 a
	Crop 1+2	
Control (+P-S)	50.0 b	
Single superphosphate (SSP)	66.8 a	70.2 a
Rock phosphate (RP)	31.7 c	6.7 c
RP+ elemental S (RP+ES)	35.3 c	22.9 b

[A] Within a crop numbers in a column followed by the same letter are not significantly different according to DMRT

In the second crop the %P recovery was higher in the three fertiliser treatments compared to the control because of higher yields in these treatments. The apparent fertiliser S recovery was not significantly different between the SSP and RP+ES treatments and both were higher than the RP treatment (Table 3) suggesting again that the elemental S in the fertiliser granules was being oxidized to plant available sulfate.

The results for crop 1 clearly showed that elemental S added to the RP had oxidized and that this led to an increase in % P recovery. The application of P to all treatments in crop 2 allowed an examination of the fertilizer S supply and the approximate doubling in the % apparent fertilizer S recovery indicated that S oxidation continued through this growth period.

Although the % P recovery in the RP treatments was only approximately 50% of that from SSP over this short experimental period the results are encouraging and indicate the need for further studies. Such studies are under way using rocks of different reactivity. Improved procedures for producing fine elemental S potentially make it possible to produce agronomically attractive fertiliser at the phosphate mine site without the need for expensive infrastructure. This is particularly important in remote areas of Australia where phosphate deposits occur and in developing countries.

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Phosphorus fertiliser requirements of rice under alternate wetting and drying irrigation in the Vietnamese Mekong Delta

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Abstract
Alternate wetting and drying (AWD) irrigation can save water in rice production while maintaining yields, but little is known about its influence on phosphorus (P) availability or fertiliser requirements. Plant-available P decreases as soil dries, causing P sorption and precipitation, and increases on rewetting, as P is released into plant-available soil fractions. This study examined how extent and frequency of wetting and drying cycles affect P availability in paddy soils. A pot trial showed dissolved inorganic P (DIP) concentrations in the soil increased with intensity of drying (continuously flooded: 1.1 mg P kg^{-1}, re-flooded after drying to 66% moisture content: 2.2 mg P kg^{-1} and after drying to 5%: 5.1 mg P kg^{-1}). In a field trial, DIP was higher following a double AWD cycle over a 30 day period (0.30 mg P kg^{-1}) than following a single AWD cycle over the same period (0.1 mg P kg^{-1}; $P<0.05$). However, Olsen P analysis detected no differences between treatments; and no differences were found in grain yields when these AWD frequencies were continued through to harvest, probably because soil P concentrations were already at an agronomic optimum for rice. Five farmers interviewed reported using P fertiliser application rates in their AWD irrigation management that varied greatly from recommended levels. The study highlighted that AWD frequency could be managed to capture increases in DIP where P is limiting. Improvement in matching P fertiliser application to crop needs is more likely to produce significant savings regardless of irrigation method.

Key words
Rice, water efficiency, irrigation, phosphorus, fertiliser application, Mekong

Introduction
Rice is conventionally flooded throughout the growing season. Climate change, inter-industry water competition, population increase and upstream damming are expected to cause water shortages for irrigated rice in the Vietnamese Mekong Delta (VMD). Therefore, rice growers are adopting AWD irrigation to lower water use. Alternate wetting and drying involves allowing water to recede below the soil surface before re-irrigation, lowering total water use (Bouman & Tuong 2001). Regimes vary in the frequency and severity of drying. When adapted varieties are used and drying is not too severe (i.e. does not exceed 30 kPa at a 15-20 cm depth), AWD can produce yields comparable to those achieved under continuous flooding (Bueno 2010). Optimum grain yield requires Olsen P concentration between 10 and 20 mg P kg^{-1} soil (Bai *et al*. 2013) and DIP greater than 0.1 mg P L^{-1} (Hossner *et al*. 1973). Cost-effective fertiliser use brings soil P concentrations to these optimal concentrations. However, little is known of the extent to which AWD irrigation influences P availability in irrigation systems or to what extent P fertiliser requirements are affected. The aim of this study was therefore to determine the influence of severity and frequency of AWD cycles on available P concentrations and rice yield in order to develop recommendations for P management practices in AWD systems in the VMD. In addition, this study evaluated P management in AWD systems in the VMD in order to adapt current P fertiliser recommendations to AWD management.

Materials and Method
Selection of phosphorus analytical methods
Phosphorus exists in in several different forms, each with a different level of availability to the rice plant. Plant-available P decreases as soil dries – causing P sorption and precipitation – and increases on rewetting, as P is released into plant-available soil fractions (Shen *et al*. 2011, Bünemann *et al*. 2013). Olsen P (Olsen *et al*. 1954) is commonly used to measure plant-available P, including both DIP, which is immediately available to the plant, and labile P, which is readily desorbed into soil solution over time. Measuring DIP in isolation gives a more accurate indication of instantaneous P availability. Therefore, this study assessed both Olsen P to measure P-availability over the life of the crop and DIP to identify fluctuations in time.

Pot Trial

A pot trial was conducted to assess the impact of AWD management on plant-available P with three irrigation treatments: continuously flooded (CF), moderate drying and rewetting (MDR) and severe drying and rewetting (SDR) (Figure 1a), using three replicates. Each replicate comprised of 15 g of homogenised moist soil packed at a 5 mm depth into 250 mL sterile plastic jars. All treatments were initially irrigated to 3 cm above the soil surface with 105 mL of deionised water. In the CF treatment, water was maintained at this level throughout the experiment. After the initial irrigation, the MDR treatment was air dried to a gravimetric water content of approximately 66%, representing a visually moist condition and a water potential of approximately -20 kPa, measured by pressure plate analysis (Cresswell 2002) then re-irrigated to 3 cm. The SDR treatment was dried to a gravimetric water content of approximately 5% before re-irrigated to 3 cm. All samples were kept in a dehydrator oven at 40°C to maintain a constant temperature while drying. Concentrations of DIP were analysed using the calcium chloride method (Rayment & Lyons 2011) 14 days after initial flooding.

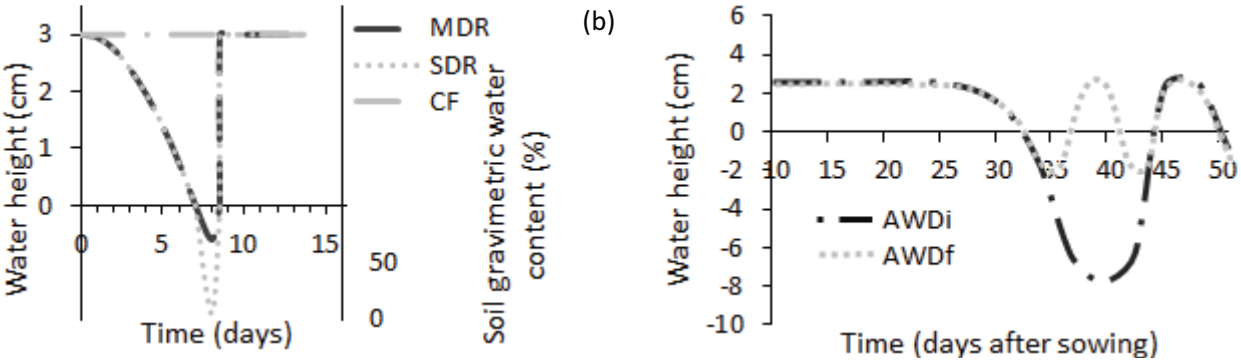

Figure 1: Schematic diagrams showing (a) severity of drying in a pot trial treatments (b) frequency of drying in field trial treatments. See text for explanation of abbreviations.

Field trial

A field trial was conducted in the 2013-14 dry season of the annual three-crop rice growing system in Bac Lieu, Vietnam. Two AWD irrigation treatments were applied at 20 days after sowing: a single AWD cycle in a 30 day period (AWD_i) a double AWD cycle over the same period (AWD_f) (Figure 1b). In AWDi, the perched water table was allowed to recede to -2 cm below the soil surface on average before re-irrigation to 1-5 cm above the soil surface, and in the AWD_f to -8 cm. Soil P was assessed 47 days after sowing but AWD cycles were then repeated at approximately 10- and 20-day intervals until harvest at physiological maturity (112 days after sowing), so that over the life of the crop AWD_i and AWD_f were irrigated 5 and 9 times, respectively.

Three soil cores were taken from the top 15 cm of soil in each treatment and combined to form a composite sample. Samples were analysed for plant-available P using the Olsen method. The soil was kept moist on analysis of Olsen P to prevent any change in available P on soil drying and results were expressed as concentrations of equivalent oven dry soil based on gravimetric water content at the sampling time. At the same time, solution samples were taken from piezometers under vacuum, which were installed 15 cm deep to collect soil water within the root zone. Solution samples were filtered through 0.45 µm filters and DIP was measured using the Phospher®3 Method (Hach Company 1998). Grain yield was measured from a 5 m^2 quadrat within each plot at harvest.

Farmer interviews

To gain an indication of fertiliser practices, interviews were conducted with five farmers practising AWD in Bac Lieu Province, Vietnam in collaboration with staff from the Can Tho University Department of Soil Science, under government approval. The interview included questions regarding current P fertiliser management practise and crop yields.

Results

Pot Trial

Irrigation had a significant influence on DIP concentration, which was 2.3 times higher under SDR (5.1 mg P kg^{-1} soil) than under MDR, and 5.1 times higher than under CF (Figure 2a).

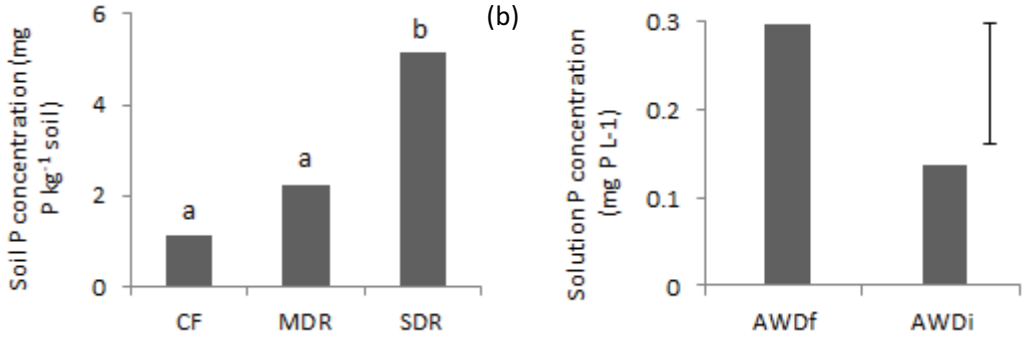

Figure 2: Dissolved inorganic P concentrations in the (a) pot trial assessing severity of drying (columns with different letters are not significantly different at P < 0.05), and (b) field trial assessing drying frequency, where the bar denotes the l.s.d (P < 0.05). See text for explanations of abbreviations.

Field trial

Irrigation treatment did not significantly affect Olsen P concentration, which averaged 10 mg kg^{-1}. However, AWD frequency did significantly affect DIP concentration in water samples (Figure 2b). DIP under AWD_f was 0.30 mg P L^{-1}, 2.1 times that under AWD_i. Irrigation treatment did not significantly affect grain yield, which averaged 5.0 t ha^{-1}.

Farmer interviews

Farmers interviewed reported a 54% variation in grain yields, and a 1266% variation in P-application rates (Table 1). Based on a P removal rate of 2.4 kg P t^{-1} (Reuter & Robinson 1997), application rates ranged from a deficit of 15 kg P ha^{-1} to an excess of 30 kg P ha^{-1}.

Table 1: Grain yield and phosphorus application under AWD irrigated rice management in Bac Lieu Province, Vietnam.

Factor	Range
Rice grain yield (t ha^{-1})	5.5-8.5
P input (kg ha^{-1})	3-42
Crop P removal (kg ha^{-1})*	13-20
Excess P applied (kg ha^{-1})	-15-30

* Assuming 2.4 kg P t-1 rice grain yield is removed at harvest (Reuter & Robinson 1997).

Discussion

The study revealed that irrigation regime affects P dynamics. The positive response of DIP to severe drying and rewetting in laboratory conditions is consistent with other research showing pulses of DIP release following remoistening of pasture soil dried to a 5% gravimetric water content or less, but not when drying has been limited to 15% (Bünemann *et al*. 2013). In the field, this pulse is most likely to occur at the very surface of the soil where drying is likely to be most severe even when soil water does not drop below the root zone (Hasegawa & Yoshida 1982). As most soluble and labile P is present in the top soil (Sims *et al*. 1998), any form of AWD may release significant P after re-irrigation where the surface soil is allowed to dry out severely.

The response of DIP to increased frequency of AWD cycles is also consistent with previous studies showing repeated cycles of drying and remoistening having a cumulative effect on available P in dryland situations. In a study of top soil from a long term pasture system over three weeks, Butterly *et al*. (2009) found an increase in up to approximately 3 mg P kg-1 between the first and third rewetting events. The current study therefore provides evidence that wetting and drying dynamics of P availability in soil under AWD irrigation are similar to those reported under dryland conditions.

However, even though DIP accumulation occurs with severe and frequent AWD, it appears this process may not influence plant-available P through the life of the crop, as AWD regime has not been found to influence the total pool of plant-available P in this or other studies (Butterly *et al.* 2011). Sensitivity of DIP, but not of Olsen P, to irrigation treatment may be a result of the scale between the two measures. Average DIP concentrations found in the present study were a minor component (0.7%) of Olsen P (calculated with a bulk density of 1.2 and gravimetric water content of 65%). Therefore, a small change in available P concentration is more likely to be detectable in measures of DIP than in the combined fractions measured using Olsen P.

Alternatively, failure to detect a change using Olsen P may indicate that any increase in DIP is provided by a corresponding decrease in labile P. The dynamics between the P fractions measured by Olsen P are worthy of further examination.

The lack of yield response from different frequencies of AWD applied in the field indicated that the tested frequencies did not create yield-limiting water stress and that any influence on DIP due to AWD was not limiting to yield. Even though only a small number of farmers were interviewed, the high variability P fertiliser management highlights the need to improve farmer understanding of crop nutrient needs and fertiliser management in the VMD as well as the potential for improvements in P fertiliser application to improve profitability. This conclusion is supported by Tan *et al*. (2004), who revealed similar variation in P application in the VMD (6-61 kg P ha-1 crop-1), regardless of plant and crop needs.

Conclusion

This study demonstrated that DIP in paddy soils can be cumulatively increased through frequent and/or severe AWD cycles, but further investigation is required to determine whether this will benefit grain in situations where P is limiting. More research is also required on the mechanism responsible for DIP release. The study also highlighted that there is potential to increase efficiency of P fertiliser management in the VMD and the need to improve farmer understanding of the P needs of rice crops. Matching plant P requirements with P fertiliser application should improve farm profit by decreasing input costs and improving crop responses to fertiliser where P is required. These changes are likely to have much greater impact on farm profitability than are relatively small changes to P-availability induced by management of AWD.

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Response of the DCAD of plantain to potassium fertilisation

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Abstract
A low dietary cation to anion difference (DCAD) in the ration fed to dairy cows prior to calving reduces incidences of milk fever post calving. Most perennial forage species have a high DCAD and should be limited in the pre calving diet. This challenge is exacerbated when these forages are grown on high K soils (e.g. areas that receive effluent applications). Plantain (*Plantago lanceolata*) is a perennial forage species with an inherently low DCAD value. This experiment was undertaken to determine the effect of fertilisation with muriate of potash on plantain mineral concentration and DCAD. Seven rates of muriate of potash (from 0 to 300 kg K/ha) were applied in July 2014 to an established plantain pasture located in north-western Tasmania. Soil and plant mineral concentrations were monitored during the following two grazing cycles. Both soil and plant K and Cl concentrations increased with increasing K fertiliser application rates. Plantain DCAD was unaffected by fertiliser application and averaged 7.6 and 15.3 meq/100g over the first and second grazings. This value was lower than those typically expected for perennial ryegrass (*Lolium perenne*). Plantain DCAD was correlated with tissue Cl concentration (correlation coefficient of -0.78) but not with tissue K, Na and S concentration, (correlation coefficient of 0.18, -0.25 and -0.22 respectively). It is concluded that plantain will maintain a low DCAD when grown on soils with a high K concentration. This suggests that plantain grown in areas with high soil K concentrations (e.g. fields that receive effluent) will be suitable for inclusion in a pre-calving diet.

Key words
Lead feeding, alternative forage species, potassium fertiliser, hypocalcaemia

Introduction

After mastitis, hypocalcaemia (milk fever) is the second biggest animal heath challenge facing dairy farmers (Roche et al. 2008). Clinical milk fever can result in death, while sub-clinical milk fever results in decreased milk production and reduced reproductive performance (Block 1984, Chapinal *et al*. 2012). Milk fever is estimated to cost $300 per clinical case and $125 per subclinical case in terms of treatment costs and lost production (Oetzel and Eastridge 2013) and consequently is a significant cost to the dairy industry.

On Tasmanian dairy farms specially formulated diets are fed prior to calving to help alleviate the incidence of milk fever. These diets (termed lead feeding diets) are often comprised of a restricted pasture allocation, grass hay and specially formulated pellets. These pellets are formulated to have a negative dietary cation to anion difference (DCAD). The DCAD of a feed/diet is based on the concentration of potassium (K), sodium (Na), chloride (Cl) and sulphur (S). It is expressed as milliequivalents (mEq) per 100gDM and is calculated as DCAD = (%Na × 43.5 + %K × 25.6) − (%Cl × 28.2 + %S × 62.5) (Lean et al. 2006). The objective of lead feeding is to provide a diet that has a DCAD close to 0 (Roche et al. 2003). This establishes the physiological processes in the cow that release of calcium from storage in her bones so it is available for the production of milk. Lead feeding pellets are relatively expensive ($700/tDM) and the feeding of the diet is often logistically difficult.

Plantain (*Plantago lanceolata*) is a perennial forb that is becoming a more popular forage species on Tasmanian dairy farms. This increase in popularity is due to its tolerance to drought and heat (Stewart 1996) and its lower fibre content nutritional value during periods when the pasture base of perennial ryegrass (*Lolium perenne*) is high in fibre (Woodard *et al*. 2008). Plantain is also unique amongst the perennial forages in that it has a relatively low and seasonally stable DCAD (Jacobs and Ward 2011, Raeside *et al*. 2012, K.G. Pembleton unpublished data). Recent research where cows grazed plantain in place of a lead feed diet identified that it was just as effective in establishing calcium cycling within the cow as a traditional lead feed diet (Hill 2014).
As perennial forages take up K in luxury amounts when it is readily available in the soil (Kresge and Younts 1962) the DCAD of pastures is particularly high when grown on fields with a high soil K availability. On dairy farms the highest soil K levels are typically found in fields close to the dairy shed as these are the areas that

receive regular applications of effluent (Gourley *et al*. 2007). Unfortunately these fields are also favoured for lead feeding as their proximity to the dairy shed makes managing the logistics of lead feeding easier.

The aim of this experiment was to determine if plantain would be a suitable alternative lead feeding option when grown in areas with a high soil K level (e.g. fields that receive dairy effluent). It achieved this by assessing how the DCAD, mineral composition and growth of plantain are influenced by increasing levels of K fertiliser applications.

Methods

The experiment was undertaken in an established field of plantain at the Tasmanian dairy research facility (TDRF) at Elliott (41.08°S, 145.77°E) in northwest Tasmania. This location has a red ferrosol soil type, a cool temperate climate and a winter dominant rainfall pattern (average annual rainfall of 1200 mm). Long term average maximum and minimum air temperatures are 19.4 and 10.3°C respectively in January and 10.4 and 4.3°C respectively in July. The field was established in December 2013 by direct drilling plantain after spray-grazing with glyphosate. The field was grazed on a rotation basis with dairy heifers or dry cows with herbicides and insecticides applied when necessary.

The experiment commenced on the June 27, 2014. After grazing 21 three by six metre plots were established over three blocks (seven plots per block). Each plot in each block received one of seven K applications which were 0, 50, 100, 150, 200, 250 or 300 kg K/ha applied as muriate of potash. A pre experiment soil test (to 100 mm soil depth) indicated that soil had 50 mg mineral nitrogen (N)/kg, an Olson phosphorus (P) level of 29.6 mg P/kg, a Colwell K level of 488 mg K/kg, a CPC S level of 15.3 mg S/kg and a pH in water of 5.7. Each plot received 40 kg N/ha and 45 kg P/ha as di-ammonium phosphate at the same time as the K treatments were being applied. The plots were allowed to grow for 70 days and then were grazed (harvest 1). Plots were then regrown for a further 29 days and then grazed again (harvest 2). The plots were stocked with enough cows to graze them to a residual biomass of 700 kgDM/ha in a 24 hours.

Immediately prior to harvest 1 and harvest 2 each plot was soil sampled by collecting 30 soil cores per plot to a soil depth of 100 mm. These samples were then dried a 40°C for 120 hours and then were milled to pass through a 2 mm screen. The milled samples were analysed for their K (Colwell extraction) and Cl (aqueous soil extraction) concentrations. After soil sampling a 1 by 6 m strip was mown from the centre of each plot with a sickle bar mower. The cut material from each plot was gathered, weighed and then sub-sampled. Each sub-sample was weighed, dried in a fan forced oven at 60°C for 48 hours and then weighed again. Dry matter (DM) content and DM yield was calculated. The dried pasture samples were milled to pass through a 1 mm screen before being analysed for their K, Na, Cl, S concentrations by inductively coupled plasma-atomic emission spectrometry after digestion with nitric acid and hydrogen peroxide. The DCAD for the forage from each plot was then calculated.

Results

There was a linear response in soil K concentration to the increasing K fertilizer applications at harvest 1 and 2 (Figure 1). There was also a linear response in soil Cl concentration at harvest 1 in response to the increasing K fertilizer application rates. No linear or quadratic response in soil Cl concentration was evident for harvest 2. Tissue K concentrations increased at a decreasing rate in response to increasing K application rates and reached a maximum of 34.8mg/kg between 250 and 300 kg K/ha. There was no linear or quadratic trends in tissue K concentration at harvest 2. For both harvest 1 and 2, tissue Cl responded non-linearly to increasing K fertilizer application rates.

The potassium fertilizer treatments affected the DM yield of plantain for harvest 1 (Table 1). The greatest yield was achieved when 150 kg K/ha were applied and the lowest yield occurred when no potassium was applied. There was no impact from the rate of potassium fertilizer on tissue Na and S concentration or on the DCAD of the forage. The DCAD of plantain was negatively correlated (r:-0.78) with plant Cl concentration (Figure 2). The correlations between DCAD and tissue K, Na and S concentrations were weak with correlation coefficients of 0.18, -0.25 and -0.22 respectively.

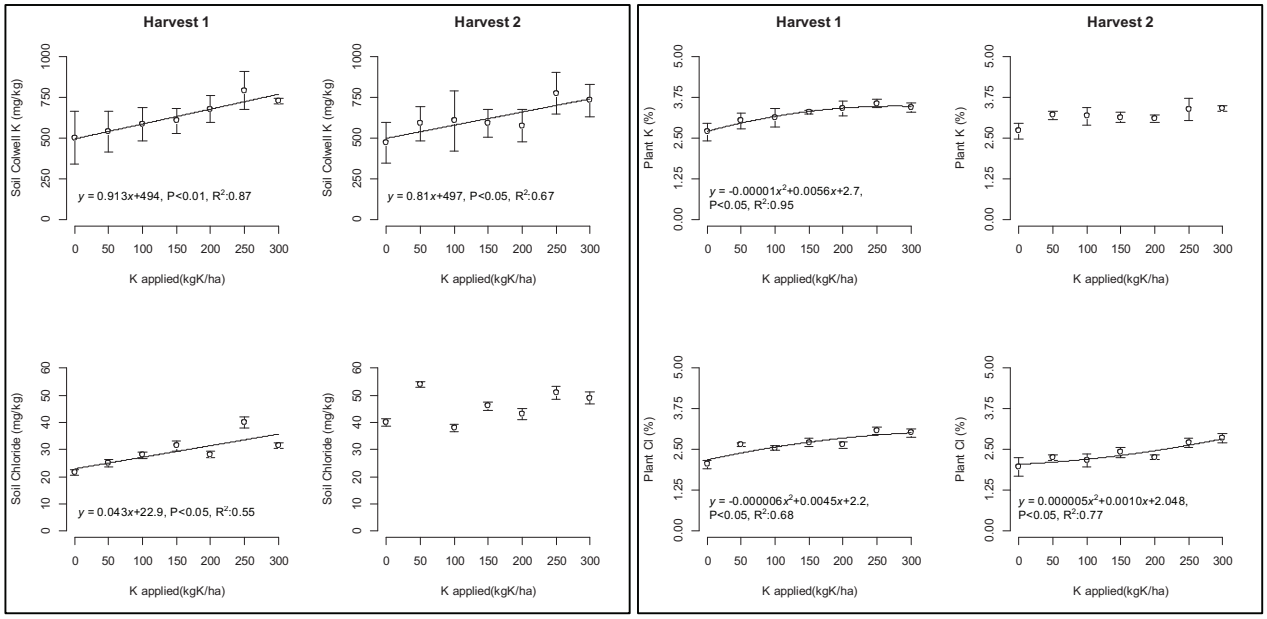

Figure 1. The response of the potassium (K) and chloride (Cl) concentration of the soil (left panels) and the plant tissue (right panels) at harvest 1 and harvest 2 to the K fertiliser application rates applied. Error bars represent the standard errors of the means.

Table 1. The impact of increase potassium fertiliser application on the yield sodium (Na), and sulphur (S) concentration and the dietary cation to anion diference (DCAD) of plantain at harvest 1 and harvest 2.

K applied (kgK/ha)	Yield (kgDM/ha)	Plant Na (%)	Plant S (%)	DCAD (meq/100g)
		Harvest 1		
0	1345 c	0.61	0.34	16.6
50	1572 abc	0.61	0.36	6.9
100	1518 bc	0.52	0.36	7.3
150	1830 a	0.47	0.34	6.1
200	1425 bc	0.44	0.35	10.2
250	1681 ab	0.45	0.34	2.3
300	1672 ab	0.52	0.35	3.9
P value	<0.05	Ns	ns	ns
SED	133	0.07	0.01	5.6
		Harvest 2		
0	1105	0.52	0.28	19.0
50	1587	0.50	0.31	20.8
100	1671	0.47	0.32	20.7
150	1513	0.44	0.30	12.1
200	1322	0.41	0.30	14.6
250	1551	0.47	0.31	11.2
300	1481	0.49	0.31	8.7
P value	ns	Ns	ns	ns
SED	267	0.05	0.01	7.2

Discussion

The DCAD of plantain in this experiment was well below the values reported for other forage species (Mckenzie and Jacobs 2002). Furthermore, it was unaffected by increasing the availability of potassium through the application of mutate of potash. This was despite an increase in tissue K concentration. The increase in tissue Cl concentration that also occurred was enough to balance out the impact that increasing the tissue K concentration had on DCAD. This was confirmed by the correlation analysis in which DCAD was most strongly correlated with tissue Cl concentration. Even at the second harvest where there was no effect from the fertilizer applications on soil Cl availability there was still no response in DCAD to the increase in soil K availability. The soil K concentrations achieved in this experiment were very high even for dairy pastures and were reflective of those often recorded for fields that regularly receive dairy

effluent (Gourley *et al*. 2007). Consequently plantain sown on such areas of a farm should still be suitable for inclusion in the pre-calving diet. A response in the DCAD of plantain to potassium fertilizer may still be observed at lower soil K levels. This experiment and the work reported in Hill (2014) highlight the opportunities that plantain presents with respect to increasing the amount of home grown forage that can be included in a pre-calving diet.

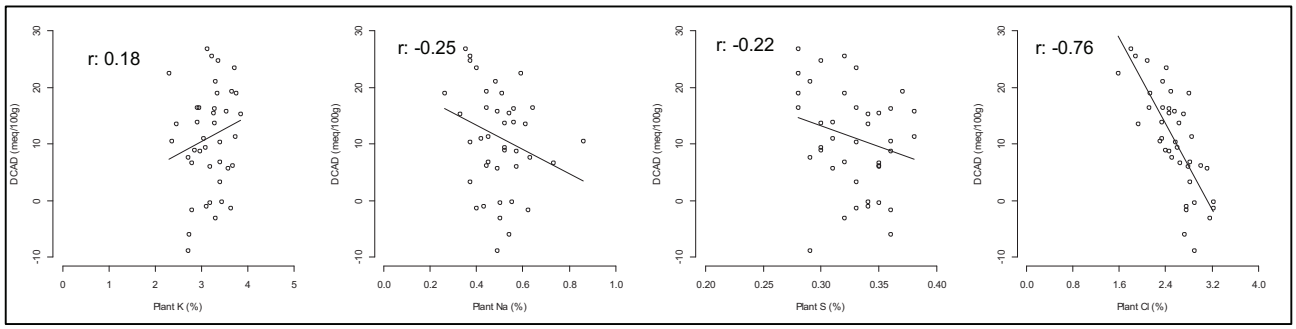

Figure 2. Correlations between tissue K, Na, S and Cl concentrations and the DCAD of the harvested forage.

Acknowledgments

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Brown manuring pulses on acidic soils in southern NSW – is it worth it?

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Abstract
Field pea and vetch are the two most popular brown manure choices in southern NSW, and their cultivation is largely dependent on the need to control herbicide resistance weeds. Brown manuring also brings other potential benefits such as the addition of soil nitrogen, and more ground cover over the summer period.

NSW DPI Pulse team established a series of experiments at Wagga Wagga in southern NSW to investigate the effects of pulse crops on the farming system if harvested for grain or brown manured. Three separate cropping sequences have been established to date, the first commencing in 2012, then 2013 and 2014. A range of legume crops were sown in year one (6 in 2012 and 7 in 2013) at three sowing times and were either brown manured at the stage of black oat anthesis or the crop was taken through to grain harvest. These were followed with two consecutive wheat crops in 2013 and 2014. There are four key messages from this work. Firstly, southern NSW growers will maximise their rotational returns by taking pulse crops through to harvest and selling the grain. Secondly, most pulse crops are likely to provide flow-on benefits to the following wheat crops provided they are well managed. Thirdly, growers should choose the pulse that best fits their farming system – the one easiest to grow and market. Finally, weeds are the major driver for brown manuring in southern NSW.

Key words
Herbicide resistance, legumes, rotation, farming system

Introduction

Pulse crops are a valuable component of farming systems in southern NSW with considerable potential to expand because of their well-documented benefits to following crops such as improved weed control, increased soil nitrogen, reduced cereal diseases and greater available stored soil water (Armstrong & Holding 2015).

Approximately 110,000 hectares of pulses (field pea, lupin, chickpea, faba bean and lentil) were sown in southern NSW in 2014 (*Pulse Australia Crop Forecast*, 9 February 2015), representing about 4% of total land cropped. Anecdotal evidence points to a further 20,000 or more hectares of vetch within the same system grown for brown manuring, hay or seed. Growers intentions to sow pulses either for grain or brown manure are generally known well in advance of sowing and very few grain crops end up brown manured as a last minute decision. The decision to follow this strategy is driven largely by the presence of weeds, particularly herbicide resistant grass weeds. Field pea and vetch are the two most popular brown manure choices. Morgan is the preferred field pea variety for brown manuring because it is taller, bulkier and more competitive with weeds. Morava and Blanchefleur are the most common vetch varieties but growers are now moving to the earlier, higher yielding variety Volga. Brown manuring also brings further benefits of addition of soil nitrogen from N_2-fixation, extra soil moisture storage as a result of the earlier "fallow" and a more protective mulch cover over the summer period (Gaynor *et al*. 2012).

These substantial benefits do come at a price – no income that year. The obvious questions are how does this strategy compare to growing a pulse for grain alone, and can productivity be recouped in the following two wheat crops? This paper attempts to address this question using three seasons of experiments conducted at Wagga Wagga in southern NSW.

Methods

Experiments were conducted at Wagga Wagga on acidic Red Chromosols, pH ($CaCl_2$) 4.5-5.0, typical for southern NSW. In 2012 a brown manure trial compared the time of sowing (TOS) of 6 legume crops either brown manured or harvested for grain. Brown manuring was carried out using two applications of non-

selective herbicides (double knock) at anthesis or early milky dough of black oats (Avena sp.). Although relatively early compared to the development of the pulse crops this timing was chosen due to the recent rise in herbicide resistant black oats requiring specialist management in the region. A wheat crop followed in 2013 and 2014. The brown manure trial was repeated in 2013 and compared 3 TOS of 7 legumes and a non-legume (wheat) crop that were either brown manured or harvested for grain. Brown manuring was again carried out at anthesis of black oats stage. In 2014 wheat (cv. Lancer) was sown across both trials to measure residual effects of pulse treatments on wheat yield and protein. Both years experienced environmental constraints of frosting and a dry finish, partially restricting full yield expression of some or all treatments. Normal agronomic practice was followed for seeding, weed and pest control and harvest. The wheat was sown with 80 kg/ha of MAP fertiliser (NPKS 10:21.9:0:1.5). No additional N was applied to the wheat crop.

Results and discussion

The Wagga Wagga climate is temperate, with long-term average annual rainfall of 530mm, and 328mm growing season rainfall (GSR) April – October. During the 2012 season there was 194mm during March, but this was followed by a drier than average GSR (160mm). Pulse crops grew well on the stored moisture with low pressure from fungal disease in the dry atmospheric conditions. 2013 was a below average year with 128mm summer rainfall, 251mm GSR and 390mm total rainfall, and was exacerbated by frosts during October. 2014 was similar with 458 mm annual rainfall and 278mm GSR and again was impacted by a dry, frost prevalent spring.

Brown manure biomass and grain yields from 2012 and 2013

In 2012 there were significant effects of TOS and variety on biomass at the time of brown manuring (Figure 1) and on final grain yield (Table 1). Greatest biomass was achieved by sowing Morava vetch early in mid-April. For later sowings in May and June field peas were equal to or more productive than vetch. Lupins did not perform well but had suffered from pest grazing (wild hares) at emergence, from which they were unable to fully recover. Grain yields up to 3 t/ha were achieved by PBA Percy field peas. Morava vetch had consistent grain yields just below 2 t/ha for each TOS despite having significant differences in anthesis biomass.

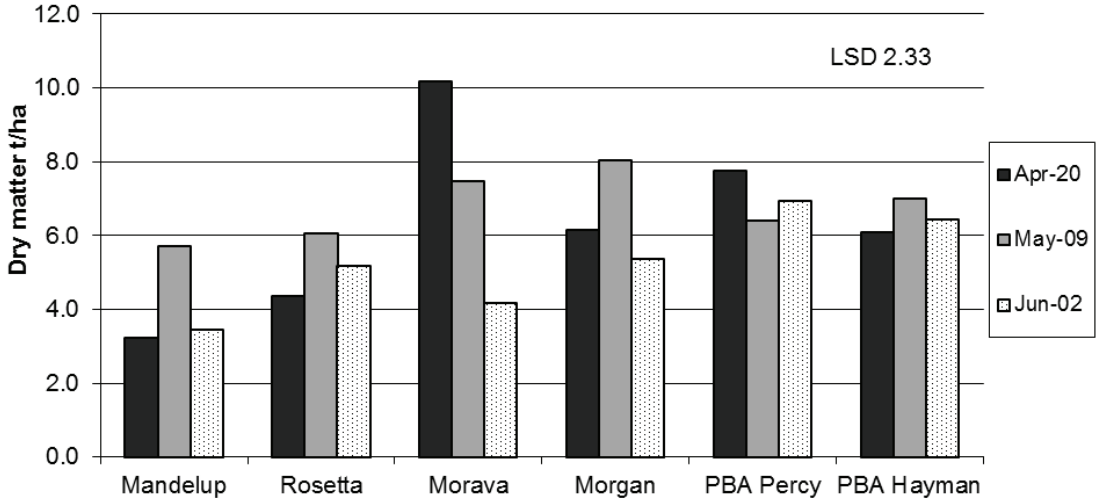

Figure 1. Above ground biomass (t/ha) of brown manures for each TOS at the timing of black oat anthesis in 2012.

Table 1. Grain yields (t/ha) of crops for brown manure at each TOS in 2012 and 2013.

		2012			2013		
		Apr 20	May 9	Jun 2	Apr 12	May 27	Jun 11
Faba bean	Fiord				2.41	2.26	1.77
Lupin	Mandelup	1.12	2.14	1.33	1.59	1.40	1.39
	Rosetta	1.64	2.79	1.71	1.42	1.60	1.54
Vetch	Morava	1.96	1.94	1.78	0.86	1.17	1.49
Field pea	Morgan	1.77	2.40	2.47	1.80	1.59	1.30
	PBA Percy	1.83	3.01	2.95	1.99	2.08	2.02
	PBA Hayman	1.27	1.77	2.27	0.64	0.57	0.62
Wheat	Lincoln				3.14	2.71	2.66
LSD			0.71			0.30	

In contrast, there were no TOS effects on anthesis biomass in 2013, and only small variety effects (Figure 2). There were no differences in anthesis biomass between the 3 field pea varieties and Morava vetch, and Rosetta lupin, Mandelup lupin and Fiord faba bean were only significantly less than Morgan field pea. The highest pulse grain yields were from faba beans sown early. Field pea grain yields again showed very little response to TOS. No treatment effects were evident in wheat grain yields (data not shown) following the 2012 treatments, but this could have been masked by frost damage. Average brown manure biomass in 2013 was substantially less than the previous season due to lower available moisture and some plant stresses associated with frost and diseases.

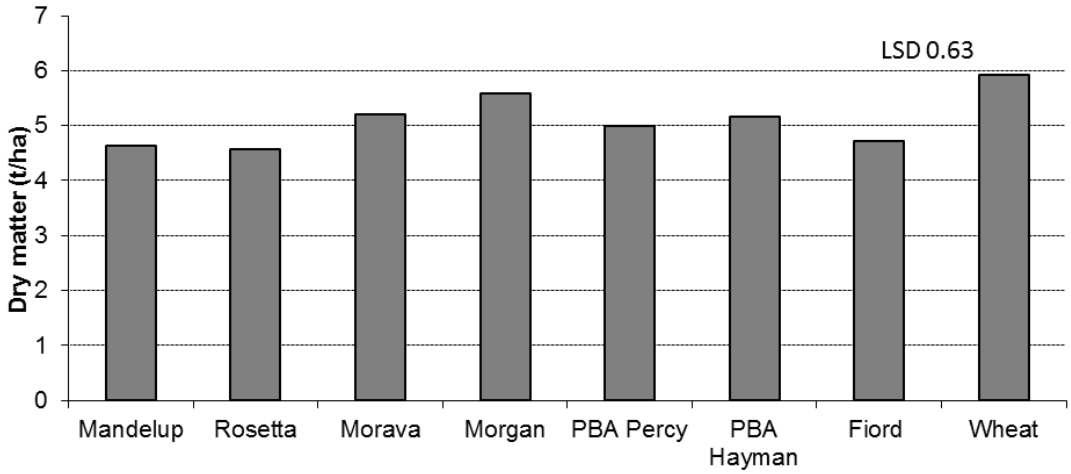

Figure 2. Above ground biomass (t/ha) of brown manure crops averaged across TOS for varieties at anthesis of black oats in 2013.

Wheat 2014 after brown manure 2013

The wheat (cv. Lancer) sown after wheat harvested for grain in 2013 yielded 2.8 t/ha in 2014 (Table 2). This was lower yielding than wheat after all of the pulses that were harvested for grain in 2013 (average 3.3 t/ha). There were no significant differences between wheat yields after any of the brown manure treatments and TOS in 2013, including the cereal (average 3.4 t/ha). However the dry spring in 2014 is likely to have restricted the yield potential and minimised the expression of any treatment effects.

The main rotation effect was seen in wheat grain protein. Grain protein of wheat after wheat rotation was well below 10% and this would generally incur a substantial marketing issue with price affected due to low protein percentage. Manuring the previous crop led to a significant increase in grain protein of 1.0 to 1.5% compared to that harvested for grain, but this is unlikely to negate the opportunity cost of manuring the previous crop for yield and protein gains alone.

Table 2. 2014 wheat grain yield (t/ha) & protein (%) after 2013 brown manure & harvested grain crops

Crop	**Variety**	**2013**	**Wheat 2014**		**Protein**		**Grade**	
		Pulse t/ha	Grain t/ha	Manure t/ha	Grain %	Manure %	Grain	Manure
Faba bean	Fiord	2.15	3.35	3.46	10.3	11.7	ASW	H2
Lupin	Mandelup	1.46	3.34	3.30	10.9	12.5	APW	H2
	Rosetta	1.52	3.30	3.46	11.1	12.6	APW	H2
Vetch	Morava	1.17	3.35	3.34	11.2	12.5	APW	H2
Field pea	Morgan	1.56	3.33	3.46	10.8	11.9	APW	H2
	PBA Percy	2.03	3.25	3.45	11.2	12.2	APW	H2
	PBA Hayman	0.61	3.38	3.37	11.5	12.0	APW	H2
Wheat	Lincoln	2.84	2.89	3.31	8.7	9.6	ASW	ASW
LSD:		0.18	0.25		0.5			

Wheat 2014 after wheat 2013 and brown manure 2012

Two years after brown manuring there were still benefits evident in the system. Wheat sown 2 years after the brown manuring trial averaged 3.5 t/ha (Table 3). There were no significant differences between crops brown manured or harvested for grain, and only a small decrease in yield for wheat grown 2 years

after Mandelup lupins compared to Morava vetch, Hayman and Percy field peas. However there remained treatment effects with more protein (about 0.5%) in the wheat following pulse crops that had been manured (12.6%) instead of harvested for grain (12.0%). There were also differences between species (Table 3), with most increase in wheat grain protein following Morava vetch and Percy field pea, and the least protein percentage following the lupin crops. This may reflect the biomass of the preceding legumes.

Table 3. 2014 wheat yield and protein after 2013 wheat after 2012 brown manure trial

2012 Crop	Variety	2014 wheat grain yield t/ha	Protein %
Lupin	Rosetta	3.46	11.7
	Mandelup	3.35	11.9
Field pea	Morgan	3.48	12.3
	Hayman	3.68	12.4
	Percy	3.64	12.7
Vetch	Morava	3.65	12.7
	LSD	0.22	0.4

Conclusions

Growing any of the pulse crops adapted to southern NSW has significant advantages for subsequent wheat yields in the first and second year compared to growing wheat on wheat. Inclusion of lupin, field pea, faba bean or vetch phases, either harvested for grain or brown manured, gave a significant boost to subsequent wheat production in these southern NSW experiments. While there were no significant differences in wheat yields following legumes either harvested for grain or brown manured, wheat grain protein content did significantly improve by 1.0 to 1.5% after brown manuring. This small but significant increase in wheat protein is still unlikely to compensate for total loss of returns from brown manuring the previous year. This suggests that in the absence of herbicide resistant weeds, growers will maximise their rotation gross margin by taking pulse crops through to harvest and selling the grain. Other studies and technical guides have shown brown manures work best when weed resistance is the major driver, and residual nitrogen and moisture conservation important but secondary considerations (Armstrong, 2015; Gaynor et al., 2012; McGillion and Storrie, 2006).

There are four key messages from this work. Firstly, southern NSW growers will maximise their rotational gross margin by taking pulse crops through to harvest and selling the grain. Secondly, most pulse crops are likely to have similar flow-on benefits to the following wheat crops provided they are well managed. Thirdly, growers should choose the pulse that best fits their farming system – the one easiest to grow and market. Finally, brown manuring in southern NSW is most effective when herbicide-resistant weeds are the major driver.

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Nutrient status of soils and crops in the high rainfall zone of Victoria and South Australia

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Abstract
Canola and wheat grown in the high rainfall zone (HRZ) of Victoria and South Australia can potentially produce grain yields over 4 and 8 t/ha, respectively. However, the average in the region are less than half these values. Such high yielding crops require substantial application of inputs, the most costly being fertilisers. Decisions about nitrogen fertiliser rates are generally based on the difference between the nutrients required for a targeted yield and the estimated amount of nutrients supplied from the soil. However, limited research has been conducted in the HRZ relating the nutrient response of crops to soil nutrient status, and critical soil test values are either not known or are estimated from other regions and soil types. An improved understanding of this relationship will reduce the risk of either under or over applying fertilisers, hence maximising returns to growers. This paper reports on a survey conducted in the HRZ to assess the status of the major and trace nutrients in soils and crops. Results from soil and plant analyses were compared to established critical values to determine if there were any common deficiencies. Survey data was used to identify sites to develop nutrient response curves to help predict the economic and production risks of under or over supplying fertilisers in the HRZ.

Key words
Crop nutrient requirement, field survey, trace nutrients

Introduction

The high rainfall zone (HRZ) of southeastern Australia (500 – 900mm rainfall/year) provides the climatic environment and soil resources in which canola can yield 3-5 t/ha and wheat can yield 9–11 t/ha with current varieties (Riffkin and Sylvester-Bradley 2008). Additionally, newly introduced winter-type canola cultivars have achieved yields over 7 t/ha under experimental irrigated field conditions (Acuña *et al*. 2011; Riffkin et al. 2012; Christy *et al*. 2013). Despite these high potentials, the current average yield is only 1-2 t/ha for canola and 2-3 t/ha for wheat, due to abiotic (e.g fertility, waterlogging, subsoil acidity) and biotic (e.g. fungal diseases, insect pests) stresses (Riffkin and Sylvester-Bradley 2008; Riffkin *et al*. 2012). Attaining yields closer to these high potential yields requires additional inputs, and the biggest single cost is fertiliser (Rural Solutions SA 2013). Greater understanding is being sought by growers when targeting high yields to reliably predict how much fertiliser to apply. Growers need to balance the risk of under applying fertiliser which limits yield against over applying fertilisers and wasting inputs. Nitrogen fertiliser requirements are generally based on the difference between the nutrients required for a targeted yield and the estimated amount of nutrients supplied from the soil. Balancing N with other essential nutrients such as P, K, S, Cu and Zn is important to attain high grain yields.

Critical soil test values for P, K and S can be sourced from The Better Fertiliser Decisions for Crops database (BFDC) for crops grown in various soils and regions. However, the database highlights that datasets are limited to "traditional" cropping regions and predominantly focused on N and P nutrition in wheat (Conyers *et al*. 2013). There are few datasets for wheat and almost no datasets for canola responses to nutrients in the HRZ of southeastern Australia. As a consequence, growers and advisers in the HRZ rely on critical soil test values and nutrient response information generated in lower rainfall environments and on different soil types. These values may or may not be valid in the HRZ.

A field survey of soil, tissue and grain conducted in southeast South Australia and southwest Victoria aims to establishing baseline knowledge about the current nutrient status of soils, and canola and wheat crops

in the region. The first year of field survey data was also used to identify field sites for nutrient omission experiments that are designed to test the validity of critical soil test values and response curves for high yielding crops in the HRZ. A second year of sampling will be conducted in 2015. This paper presents the findings for the first year.

Methods

Soil, tissue and grain samples were taken from commercial crops in southeast South Australia and southwest Victoria from April to August 2014 with sites ranging from Frances to Inverleigh. All samples were analysed for nutrients at Nutrient Advantage Laboratories, Werribee, using commercially available analysis methods. Soils were sampled in South Australia at 12 sites prior to fertiliser application and were subjected to a comprehensive soil nutrient analysis in increments: 0 to 10 cm, 10 to 30 cm, 30 to 60 cm and 60 to 100 cm. Tissue samples (39) were taken from three wheat cultivars (cv. Revenue, Bolac and Derrimut) at Growth Stage (GS) 31 and triazine-tolerance canola at Growth Stage 3.3 (bud first visible) by sampling youngest emerged leaves. Leaves were collected from at least 100 wheat or canola plants in July and August at each site. Grain samples of the same wheat cultivars and canola type were taken from two sources. The first source was the crops sampled for soil and tissue analysis in southeast South Australia. The second source was grain from 49 farms in the target region that delivered to GrainCorp® receival sites at Geelong and Naracoorte. All tissue and grain samples were analysed for nutrient concentration of B, Ca, Cu, Fe, Mg, Mn, P, K, Na, S, Z, N, Mo ('T3' test).

Results

Soil analysis from this first year of field sampling showed that some paddocks in southeast South Australia had low soil nutrient concentrations for S, Cu, Mn and/or Zn, and this is consistent with earlier surveys (Donald and Preston 1975) (Table 1). Most other nutrients in South Australia were deemed adequate according to critical soil test values (Peverill *et al*. 1999; GRDC 2013).

Table 1: Nutrient analysis of soil in southeast South Australia immediately prior to the 2014 cropping season for 0-10 cm (n=12) and 10-30 cm (n=12).

		Critical value in	0-10 cm				10-30cm			
Soil analysis	Units	0-10 cm layer	Min.	Average	Max.	StDev	Min.	Average	Max.	StDev
pH (1:5 Water)		-	5.5	7.5	8.6	1.1	7.2	8.2	8.7	0.6
pH (1:5 CaCl2)		-	4.9	7.0	7.9	1.1	6.1	7.4	8.1	0.7
Mineral N (NO3 + NH4)	mg/kg	-	2.7	22.7	85.0	23.9	3.6	13.5	30.2	9.1
Phosphorus (Colwell)	mg/kg	25	23.0	49.9	73.0	14.9	5.3	10.5	18.0	4.1
Phosphorus Buffer Index (PBI-Col)		-	57.0	118.1	180.0	44.4				
Sulfate Sulfur (KCl40)	mg/kg	5	4.4	23.6	62.0	21.2	3.3	13.9	39.0	10.5
Calcium (Amm-acet.)	Meq/100g	1	4.0	28.0	55.0	18.6	6.5	25.8	41.0	13.7
Potassium (Amm-acet.)	Meq/100g	0.25	0.3	1.7	4.9	1.5	0.4	1.1	3.2	0.9
Magnesium (Amm-acet.)	Meq/100g	0.2	1.0	5.1	13.0	4.3	1.8	7.6	15.0	3.4
Sodium (Amm-acet.)	Meq/100g	-	0.3	0.8	3.9	1.1	0.2	1.6	3.1	1.2
Cation Exch. Cap.	Meq/100g	-	6.2	38.5	61.6	21.2	17.5	36.0	58.6	14.3
Calcium/Magnesium Ratio		-	2.5	6.4	13.0	3.7	0.8	4.8	18.0	5.2
Copper (DTPA)	mg/kg	0.4	0.3	0.8	1.3	0.3				
Iron (DTPA)	mg/kg	-	7.2	144.3	530.0	187.3				
Manganese (DTPA)	mg/kg	5	0.9	3.9	8.8	2.7				
Zinc (DTPA)	mg/kg	0.4	1.1	3.5	12.0	3.3				
Boron (Hot CaCl2)	mg/kg	0.5	0.9	2.0	4.3	1.1				

The nutrient concentrations of canola at 'first bud visible' (Stage 3.3) were generally above the reported critical values, although some crops tested had micronutrients applied either with fertiliser or as foliar supplements. Nutrient concentrations in wheat at GS31 were generally above critical values for major nutrients although several had low concentrations of Mg, Cu and Zn (Table 2).

Grain sourced from GrainCorp® provided a sample of grains from a cross-section of grain enterprises in the region including growers operating low and high input systems. Grain nutrient concentrations were considered adequate for most nutrients in most paddocks although copper concentrations in canola (1.6 – 3.2

mg/kg) were at the lower end of the range whilst P and K concentrations in wheat were often below critical values proposed in Reuter *et al*. (1997) (Table 3).

Table 2: Nutrient analysis of wheat tissue at GS31 (n = 23) and canola tissue at 'first bud visible'(n = 16) sampled during the 2014 cropping season. Critical values are minimum value for adequate nutrition as sourced from Reuter *et al.* (1997).

		N	P	K	S	Ca	Mg	Na	Mn	Fe	B	Cu	Zn	Mo
	unit	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Wheat tissue at GS31	Critical value	35000	3000	24000	1500	2100	1500	-	15.0	-	5.0	3.0	20.0	0.1
	Min.	37000	2300	25000	2600	1300	800	100	37.0	57.0	2.3	1.1	13.0	0.1
	Average	52391	3848	38435	3935	2970	1374	374	93.9	99.0	4.0	5.0	27.6	0.6
	Max.	67000	5600	48000	5200	5000	2200	700	230.0	180.0	7.9	9.4	71.0	3.5
	StDev	8500	1016	6207	778	1091	376	203	44.9	29.7	1.3	2.4	14.9	0.8
Canola tissue at 'first bud visible'	Critical value	53000	3200	28000	4700	1400	2100	-	-	-	22.0	4.0	22.0	-
	Min.	62000	6400	29000	7000	5700	2200	600	25.0	78.0	27.0	3.0	27.0	0.2
	Average	72625	8444	33250	8269	9456	3294	2444	50.3	154.5	32.3	5.4	52.9	0.4
	Max.	83000	12000	38000	9900	12000	4900	4400	93.0	670.0	39.0	7.4	82.0	1.3
	StDev	6622	1275	2769	747	2061	641	1121	19.9	145.7	3.7	1.5	13.2	0.3

Table 3: Nutrient analysis of wheat (n = 35) and canola (n = 28) grain sampled at the end of the 2014 cropping season. Critical values are minimum value for adequate nutrition as sourced from Reuter *et al.* (1997) and Norton (2014).

		N	P	K	S	Ca	Mg	Mn	Fe	B	Cu	Zn	Mo
	unit	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Wheat grain	Critical value	-	2700	5000	1200	-	-	20.0	-	2.0	2.5	15.0	-
	Min.	17000	1300	2900	1200	200	700	5.9	17.0	1.3	1.9	12.0	0.1
	Average	22171	2589	3883	1531	340	1029	38.6	34.1	2.3	3.4	22.5	0.2
	Max.	26000	3900	5900	1800	500	1300	58.0	50.0	3.2	4.9	37.0	1.0
	StDev	2332	589	572	155	69	127	12.3	6.9	0.4	0.8	6.7	0.2
Canola grain	Critical value	19000	3500	-	3600	-	-	10.0	-	1.0	3.0	15.0	
	Min.	34000	2900	5300	3500	1800	2300	22.0	35.0	11.0	1.6	21.0	0.1
	Average	37000	5400	6489	4182	3246	3007	36.3	99.1	15.4	2.4	34.8	0.3
	Max.	41000	8900	7700	4800	4400	3600	45.0	510.0	19.0	3.2	56.0	0.5
	StDev	1785	1423	815	371	614	318	5.5	100.7	2.2	0.4	6.5	0.1

Discussion

This snapshot of crop nutrient status in the HRZ of southeast Australia suggests that overall plant nutrition is adequate for current grain yields. However, there is a broad range of values for some nutrients in soil and tissue, so there are opportunities to improve nutrition for those crops. There was generally no relationship between soil nutrient status and plant nutrient status at the South Australian sites except possibly Cu in tissue. Similarly, relationships between soil and grain nutrition were also lacking in larger datasets sourced from National Variety Trial (NVT) sites (Norton 2012, Norton 2014). This is important given nutrients P, K and S and some trace elements are often applied at sowing based on critical soil test values rather than on how much nutrient will be removed by a crop.

Canola tissue tests consistently showed higher nitrogen and lower calcium concentrations in the youngest mature leaves than required for adequate nutrition. This could be a result of cold conditions slowing crop growth and nutrient movement through the plant, rather than a low soil supply. This highlights the need to consider weather conditions at the time of sampling when interpreting tissue analysis as part of an in-season fertiliser program.

Grain nutrient concentrations from this random sampling of canola crops were similar to grain collected from NVT sites in the same regions (Norton 2014). However, grain nutrient concentrations of P, K, S, Ca and Mg were lower in wheat grain collected in 2014 than in wheat grain sourced from NVT sites in southeast South Australia (Norton 2012). This difference between datasets may be due to the wheat grain largely

being sourced from southwest Victoria rather than southeast South Australia. Whilst these grain nutrient concentrations can be a useful guide, the interpretive values are not clear for Australian conditions.

Future nutrient management research in the HRZ aims to determine the fertiliser strategies needed to meet nutrient demand when targeting higher grain yields and test the validity of critical nutrient values for high yielding crops using nutrient omission experiments in the field. Currently, the cost of applying sufficient fertiliser to achieve an 8 t/ha of wheat crop in southwest Victoria is estimated to be $216 (Andrew Speirs, pers. comm.) on a soil with non-limiting K and S and no provision for nutrient replacement. Even though a fertiliser program to meet those demands would cost roughly 1 t/ha of wheat, at this stage most growers and agronomists consider the economic risk of incurring such fertiliser costs are too high. The opportunity cost of not using these higher rates of fertiliser needs to be better understood by growers and agronomist so that the yield potential of this region can be achieved.

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Estimating in-crop nitrogen mineralisation in dryland cropping systems of southern Australia

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Abstract
Nitrogen (N) derived from mineralisation of organic matter is believed to contribute a significant proportion of crop N uptake. Growers and agronomists can utilise a range of approaches to predict how much N will likely mineralise during the growing season, and in turn estimate crop fertiliser requirement. However, it is unclear how significant this source of N is in different cropping systems and how it is affected by environmental conditions such as rainfall. We measured net in-crop N mineralisation in selected treatments of two long–term rotation/tillage experiments located in a low rainfall (325 mm; Calcarosol) and medium rainfall (425 mm; Vertosol) environments in 2012, as well as N0 treatments from three wheat and three canola N management trials, between 2012 and 2014. Predictions based on different simple calculators for estimating N mineralisation were compared against net in-crop N mineralisation (ICM) as measured by crop N uptake and nitrate concentration in soil profiles at planting and harvest. In this study ICM values ranged from 8 kg/ha to 113 kg/ha. The amounts of nitrogen predicted by the simple calculators were between 8 and 101 kg/ha. Correlations between ICM and the Ridge calculation were generally poor. The strongest correlation (R^2=0.74) was achieved for wheat grown on Vertosols, but only when the lucerne rotation was excluded and seasonal rainfall was known.

Key words
N management, lucerne, wheat, crop N, profile nitrate, prediction methods

Introduction
Farmers constantly seek to improve their profitability by better managing nitrogen (N) to increase crop yields and minimise N losses. Angus et al. (1998) found in-crop soil N mineralisation supplied a significant proportions of crop N uptake during the season on acid soils in south-eastern NSW with mean annual rainfall of 520 – 700 mm. Nitrogen mineralisation is affected by a range of factors including climate, management (rotation and tillage) and soil properties (organic matter, moisture, pH etc.) (St. Luce et al. 2011). In contrast to south-eastern NSW, large areas of the cropping belt of Victoria (and South Australia) have alkaline soils and annual rainfall of < 420 mm, and are dominated by continuous cropping with little use of pastures, so the relative importance of in-crop N mineralisation to crop nutrition may be markedly different.

There are several ways to predict N mineralisation, including soil tests, computer modelling and simple calculators. Aerobic and anaerobic soil incubations are reportedly correlated with crop N uptake and yield (Keeney and Nelson 1982). These methods are time-consuming and unsuited to commercial analysis. Instead, farmers and agronomists rely on simple calculators, but the question is often raised as to how well these methods predict N mineralisation in the field. In this paper, we briefly examined (i) the significance of in-crop N mineralisation in current cropping systems in the low-medium rainfall areas of Victoria and (ii) the accuracy of some currently available approaches to predict in-crop N mineralisation.

Methods
Soil and plants samples were collected in 2012 from two long-term trials 'MC14' (Walpeup: 35°S07'S, 141°59'E, elevation 85 m asl) and SCRIME (Longerenong: 36°40'S, 142°18'E, elevation 155 m asl). MC14 is located on a Calcarosol (Isbell 1996), with a long-term average annual rainfall of 325 mm. The treatments sampled were the wheat phase of the Wheat/ Pasture/ Fallow (WPF) and Wheat/ Fallow (WF) rotations for both conventional (CV) and direct drill (DD) tillage treatments. Single superphosphate was the only fertiliser applied. Soil samples were also collected from the wheat-phase plots of four treatments in SCRIME; Continuous Wheat (WWW), Canola/Wheat/Pulse (CWP), 3-year Lucerne/Fallow/Canola/Wheat/Pulse (LLLFCWP) and Fallow/Wheat/Pulse (FWP). SCRIME is located on an alkaline Vertosol (Isbell 1996), with

an average annual rainfall of 425 mm. At sowing, urea (8.1 kg N/ha) was applied to all wheat plots. Further details of these trials can be found in Armstrong et al. (2015), Latta and O'Leary (2003) and Vu et al. (2009).

Samples were also collected from the N0 treatments of the wheat and canola trials conducted as part of the NANORP program, between 2012 and 2014. These trials were conducted predominately on grey Vertosol soils, except for 2012 canola crop which was located on a Sodosol (Isbell 1996).

Soil cores (1.2 m deep) were taken at pre-sowing and post-harvest. Soil samples were air-dried (< 40°C) and ground (< 2 mm). Soil nitrate concentration determined colorimetrically on a Lachat™ Flow Injection Analyser, after extraction with 2 M KCl (1:10) (Searle 1984). Total organic C for SCRIME and MC14 and total N for SCRIME were obtained from F Robertson (DEDJTR, Hamilton). Total N data for MC14 came from samples collected in 2010. Total N of grain and straw was analysed by combustion using a Leco™ TruMac analyser. In the absence of straw samples for MC14, values were determined using a nitrogen harvest index (NHI) of 0.7. Total N % for the canola seed were calculated by dividing protein by 6.25.

Net In-crop mineralisation (ICM) was determined using the calculation outlined in Armstrong et al. (1999) and compared to a range of simple calculators. R^2 values were compared.

ICM (kg N/ha) = $(C_N \times 1.1) + SN_M - SN_P$ …. *Eq1*
Where C_N is the above-ground crop N (kg N/ha) at maturity. 1.1 is a correction factor for below-ground N. SN_P and SN_M are the soil profile nitrate (kg N/ha) at planting and maturity, respectively. The equation was modified to account for N fertiliser additions.

Net N mineralisation (kg N/ha) = OC (%) × (1/ Soil C: N ratio) × bulk density (Mg/m^3) × (% N that mineralises/ 100) × 10,000 …. *Eq2* (Baldock, Generic yield & N calculator, URL: http://www.clw.csiro.au/products/ncalc/) where OC= organic carbon. %N that mineralises was set to 5% for Vertosols and 3% for Calcarosols.

N mineralisation (kg N/ ha) = 0.15 × OC (%) × GSR …. *Eq 3* (Peter Ridge, unpublished)
GSR: Growing season rainfall. Long-term averages for Wimmera 284.3mm and MC14 214.6mm

N mineralised (kg N/ha) = Total N (%) × % mineralised (total) × Cumulative monthly mineralisation (%) (sowing to flowering) …. *Eq 4* (Nitrogen Management Workbook, Incitec Pivot Pty Ltd)

Results & Discussion
Wheat yields ranged from 1.1 to 5.8 t/ha and crop N (above- and below-ground) varied from 27 to 179 kg N/ha. The highest yield and N uptake for wheat was obtained from the FWPl rotation at SCRIME (Table 1). Canola yields ranged from 0.63 to 2.39 t/ha; crop N uptake mirrored these yield results.
ICM values ranged from 8 kg N/ha in a late sown Canola crop, to 113 kg N/ha for wheat in the LLLCWPl treatment at SCRIME (Table 2). The lowest estimate of N mineralisation obtained using with the Ridge (season) method, at Walpeup, reflecting the low GSR (94 mm) for that season.
Most of the correlations between the Ridge equation and ICM were poor (Table 3). An R^2 of 0.1 and 0.07 was obtained for all treatments across all crops, for the long term average and seasonal prediction, respectively. The strongest correlations were achieved with SCRIME and MC14 (R^2= 0.63), or SCRIME and NANORP data (R^2= 0.68 and 0.74), but only when the LLLCWPl rotation was excluded. These methods also rely on predictions of GSR before the start of the season. Angus et al. (1998) suggested the impacts of pasture on mineralisation extended for little more than a year after the pasture phase. These results suggest the preceding 3-year lucerne phase had a significant residual effect on N mineralisation 2 years after pasture termination. The calculators appear unable to account for slow mineralisation of lucerne residues, possibly located below 10 cm in the soil profile.

Table 1. Plant and soil data for SCRIME and MC14 2012 and NANORP wheat and canola, 2012-2014. Crop N includes shoot and root. Units in kg N/ha unless specified. GSR = Growing season rainfall for the season. *n/d* = no data. W- wheat; C – canola; Pl – pulse; F – fallow ; L – Lucerne, P-pasture; DD – direct drill; CV - conventional tillage. TN= Total N, OC= Organic C

Trial	Year	Treatment	Grain yield (t/ha)	Crop N	Sowing NO_3-N	Harvest NO_3-N	GSR (mm)	TN (%)	OC (%)	Soil C:N ratio
SCRIME	2012	WWW	2.7	73	45	6	241	0.08	1.0	10.8
		CWP	3.8	94	54	8		0.07	0.99	10.9
		LLLCWPl	3.1	154	73	39		0.11	0.99	9.3
		FWPl	5.8	179	129	6		0.07	0.89	11.8
MC14	2012	WF (DD)	1.1	41	115	84	94	*n/d*	0.56	*n/d*
		WF (CV)	1.1	42	45	38		*n/d*	0.55	*n/d*
		WPF(DD)	1.5	52	213	170		0.13	0.73	5.8
		WPF(CV)	1.3	47	208	185		0.09	0.54	6.0
NANORP(1)	2012	Wheat	2.4	58	26	4	257	0.12	0.96	8.2
NANORP(2)	2013	Wheat	3.0	65	21	14	329	0.12	1.10	9.4
NANORP(3)	2014	Wheat	1.3	27	38	22	166+31*	0.10	0.78	7.6
NANORP(4)	2012	Canola	1.1	51	41	11	257	0.14	1.14	8.4
NANORP(5)	2013	Canola	2.4	110	63	13	329	0.12	1.22	10.1
NANORP(6)	2013	Canola	0.6	16	22	10	313	0.12	0.98	8.5

*31 mm irrigation

The percentage of total N mineralised (IPL) tended to under-predict N mineralisation, except for the 2012 canola and the 2014 wheat. This method was developed in Queensland and may not be appropriate for cropping systems in southern Australia. Queensland cropping relies heavily on stored water, with most rainfall occurring during the preceding warm to hot summer fallows when mineralisation potential is high.

Table 2. ICM and simple calculators for SCRIME and MC14 in 2012, and NANORP wheat and canola 2012-2014. Units in kg N/ha unless specified. W- wheat; C – canola; Pl – pulse; F – fallow ; L – Lucerne, P-pasture; DD – direct drill; CV - conventional tillage. Season = GSR for trial year. LTA =Long-term average GSR. *n/d* = no data. Using total N % from tables assumed 3% mineralised (Red brown earths) for Calcarosol and 5% (Plains soil) for Vertosol and Sodosol, and cumulative monthly mineralisation potential of 40% (April- Oct)

Trial	Year	Treatment	ICM	Net N mineralised	Ridge (season)	Ridge (LTA)	% N mineralised
SCRIME	2012	WWW	41	48	36	42	15
		CWPl	40	48	36	42	15
		LLLCWPl	113	56	36	42	21
		FWPl	48	40	32	38	14
MC14	2012	WF(DD)	32	*n/d*	8	18	*n/d*
		WF (CV)	35	*n/d*	8	18	*n/d*
		WPF (DD)	35	59	10	23	15
		WPF (CV)	24	42	8	17	11
NANORP (1)	2012	Wheat	36	64	37	41	23
NANORP (2)	2013	Wheat	58	65	54	47	23
NANORP (3)	2014	Wheat	23	46	23	29	20
NANORP (4)	2012	Canola	22	101	44	49	27
NANORP(5)	2013	Canola	59	61	60	52	24
NANORP (6)	2013	Canola	8	60	46	42	23

Table 3. Correlations (R^2) between In-crop N mineralisation (ICM) and the two "Ridge" calculators. Season = GSR for trial year. LTA = Long-term average.

Data	Ridge (LTA)	Ridge (Season)
All treatments	0.10	0.07
Wheat data only	0.27	0.23
Wheat data excluding LLLCWPl	0.50	0.56
SCRIME+ MC14 excluding LLLCWPl	0.63	0.63
SCRIME + NANORP wheat excluding LLLCWPl	0.68	0.74

The ICM method does have limitations. This calculation does not take into account any potential losses from the system, ie through volatilisation or denitrification (Armstrong et al. 1999). The ICM calculation in our study utilised NO_3 data only, due to the air-drying of samples before analysis.

Conclusions

This study, which examined a limited number of soils and seasonal conditions, suggests that in-crop mineralisation of N can make a significant contribution to N supply of wheat. Current simple tools for predicting in-crop N mineralisation in the cropping systems of Victoria, however have poor predictive ability, at least under the conditions of this study, especially when pasture legumes are part of the rotation.

Acknowledgements

We acknowledge M Brady and R Perris for management and DEDJTR for funding of MC14 and SCRIME. Soil N and C data provided by the Soil Carbon project (F Robertson et al). Thank you to the Horsham soils team (DEDJTR) for technical assistance. The GRDC provided operating (through DAN00168), La Trobe University for provision of a scholarship and DEDJTR for scholarship top-up to KD and provision of research facilities.

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Can advances in climate forecasts improve the productive and environmental outcomes from nitrogen fertiliser on wheat? A case study using POAMA for top-dressing wheat in South Australia

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Abstract
We used APSIM to compare the profit and risk (economic and environmental) for a farmer in the medium rainfall zone of South Australia who applied the same amount N to wheat every year with a farmer that was guided by POAMA to tactically change rates. Over the 30 year period from 1981 to 2010 a farmer following POAMA would have received the correct guidance 19 times and incorrect guidance 11 times. Depending on the amount of nitrogen (N) used, following POAMA increased the gross margin by $23 or 9%. Forecasts didn't reduce the risk of nitrous oxide emissions or N leaching. Under the assumptions of this simulation study, the most economically sound N strategies come from a focus on fertiliser N use efficiency which keeps rates at levels where losses to de-nitrification or leaching are minimal.

Key words
Nitrogen use efficiency, seasonal climate forecast, APSIM modelling,

Introduction
The use of N fertiliser is a major source of yield and profit for Australian grain farmers. At the same time, N fertiliser represents a significant cost and hence a source of risk when crop demand is less than expected. N fertiliser can be a pollutant through losses as runoff and leaching. Recently there has been increased attention to nitrous oxide as a potent greenhouse gas. The need to maintain and increase profitability of N while reducing the economic and environmental risk requires a knowledge-intensive approach that takes into account the supply of N from the soil and fertiliser and the demand of N from the crop. Growing season rainfall explains most of the year to year variation in crop demand. Seasonal climate forecasts (SCF) have been available in Australia since the early 1990s. There have been many studies on the use of SCF on N decision making in wheat. Early studies such as Marshall et al 1996 and Hammer et al 1996 focussed on the grains industry in Queensland using phases of the Southern Oscillation Index. In a recent study Asseng et al 2012 reported on the dynamic climate model POAMA for N on wheat in West Australia. This study set out to investigate the value of POAMA for a simple simulation exercise of top dressing decision on wheat in South Australia. As with any analysis, the conclusions are sensitive to the assumptions.

Methods
For a wheat crop with a given level of starting soil N, the response to top-dressed N in early August (a common farm practice) is determined by both the climate up to that point and the climate for the rest of the season. In this simulation exercise we focussed on the season finish and sought to avoid confounding the results with a range of starts to the season. To achieve this, 30, daily climate files were created using the same data from the 1st of January to the 10th of August but with different data for each year for August 11th to December 31st. This raises the question of what daily data to use for 1st January to 10th of August. A single year is preferable to any averaging of daily data, but it is not obvious which year to select. Simulation runs with APSIM showed that a combination of biomass and soil water on the 10th of August were good indicators of final yield and N response. Probability distributions of biomass and soil water on the 10th of August were generated using a mid-maturity wheat cultivar sown each year on May 15th into a soil characterised in APSIM (Light clay over medium clay over heavy clay (Hart No284)) with a Plant Available Water Capacity of 183mm. The initial soil water, soil N and surface organic matter were reset on Jan 1st every year. The soil N was set to 60kg/ha in the top 60cm plus a further 12kg/ha at lower depths. The surface organic matter was set at 1000kg/ha with a C:N ratio of 80.

From the probability distributions of biomass and soil water we selected a year that represented below average (1.1 t/ha biomass and 45 mm ESW), average (1.6 t/ha biomass and 73mm ESW) and above average (2 t/ha biomass and 115 mm ESW). In this paper we are reporting the results for the below average start. For each of the 30 years we simulated yield, leaching and de-nitrification as a result of topdressing 0 to 300 kg of N. The South Australian gross margin handbook was used to provide the 5-year average of ASW wheat at $270/tonne, a growing cost (excluding N) of $190/ha, and a nitrogen fertiliser cost of $1.30 per kg.

We accessed gridded rainfall forecasts from POAMA-2(M24) for the 30-year period 1981 to 2010 and used simple spatial interpolation to obtain station level data for Brinkworth. An above/below median forecast was recorded for a year if the mean of the 33 ensembles for that year was above/below the median of the ensemble means in the other 30 years. When compared with historical data for Brinkworth the forecast was correct (e.g., below median when below median was forecast) 19 years and incorrect 11 years.

Results

As shown in the All Years response in Figure 1(a), topdressing with N lifts simulated yields from 1.5t/ha to 2.7 t/ha (about 80%). Separating the response into above and below median rainfall years highlights the strong influence of August to October rainfall. This is evident in both the agronomic response curves (Figure 1a) and consequent economic response curves (Figure 1 b). The comparison of agronomic and economic responses to N in Figure 1a and b shows that when the cost of N is taken into account, the highest gross margin will be at a lower rate than the highest yield. While it is obvious that adding N past the maximum yield wastes money, using the average response curve (shown in Figure 1b) leads to over fertilising in below median seasons and under fertilising in above median seasons.

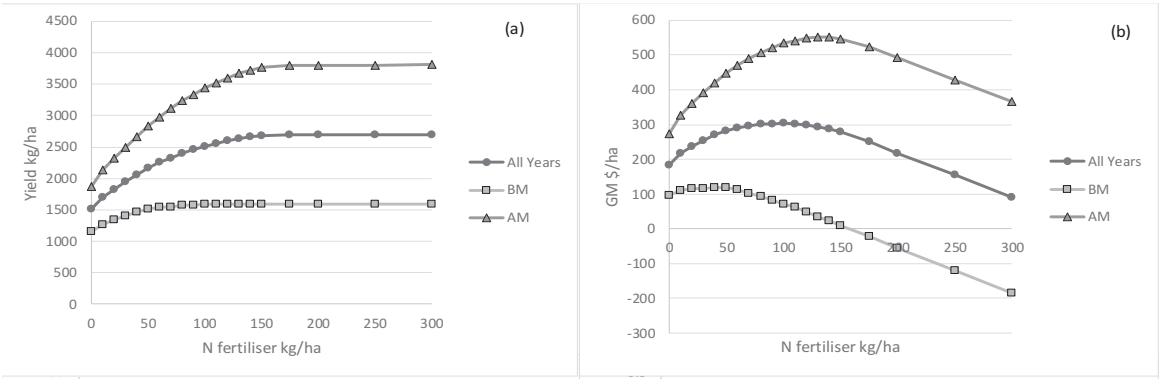

Figure 1(a) Average simulated response of yield and (b) gross margin (right panel) to fertiliser rate for 1981 to 2010 (All years), average of the 15 below median years (BM) and average of the 15 above median years (AM). The above and below median years are determined by rainfall from August 11th to the end of October. The assumptions for the gross margin are detailed in the methods.

Figure 2 reinforces the highly variable year-to-year response to top dressed N. In a high yielding year like 1992, shifting from 10 kg/ha to 70 kg/ha almost doubled the gross margin from $405/ha to $725/ha. This is due to a simulated yield increase from 2.4 t/ha to over 4t/ha. In other years, such as the El Nino drought of 2006, the simulated yield was less than 1t/ha and adding N only increased the loss.

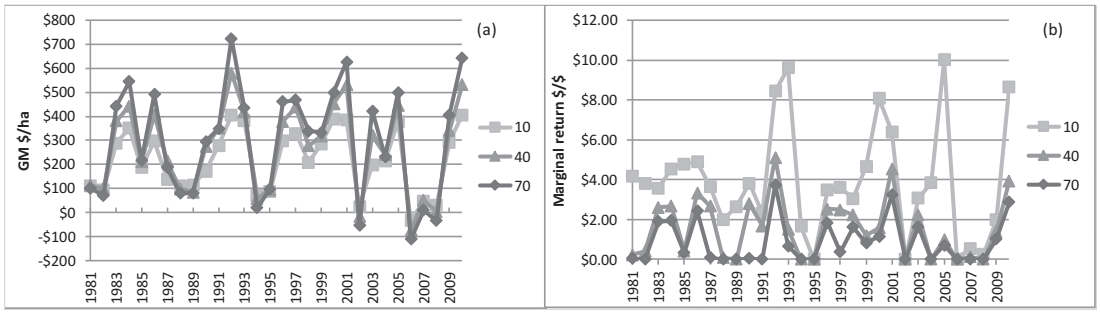

Figure 2 (a). Time series of simulated gross margin and (b) marginal return (right) for topdressing with 10, 40 and 70 kg/ha. The marginal return graph for 40 kg/ha is the extra profit ($/ha) gained by increasing the rate from 30kg/ha to 40kg/ha divided by the cost ($/ha) of adding the extra10kg/ha.

Figure 2b shows that the return to investing in N topdressing fluctuates from year to year. As expected, the first 10 kg/ha of N will always have a much higher return than any further increase, but there are years when the return for even the first 10 kg of N is less than one dollar for a dollar invested. Farmers should hope to at least receive $1.10 for each $1 invested. Higher rates greatly increase the risk of the return falling below $1.00 or $1.10. Figure 3 shows the declining marginal return with increased rates of N. Tracking the "All years" line in Figure 3 shows that on average, the marginal return over the 30 year period for the first 10 kg N/ha is about $4.00. The return for shifting the topdressing rate from 30 to 40 kg N/ha is $1.57 and for shifting from 60 to 70 kg N/ha is $0.89. Figure 3 also shows the impact of spring rainfall. The above-median curve drops below the $1.10 return in the step from 90 to 100 kg/ha. In contrast, in the below- median years, even the step from 20 to 30 kg/ha drops below this line.

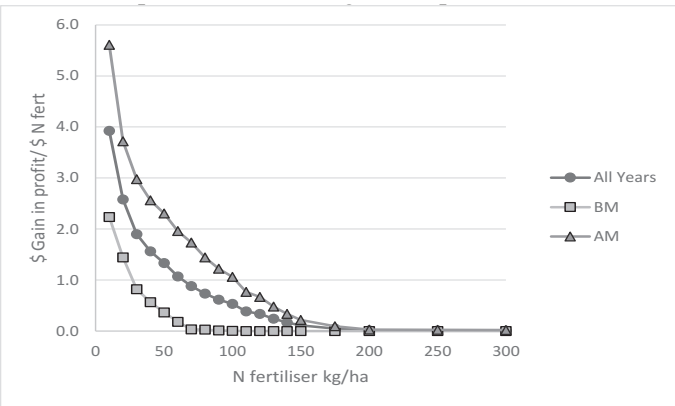

Figure 3. Marginal return for each kg of N assuming that wheat is $2.50/kg and N is $1.30/kg. The points on the graph are simulations for each 10 kg of N top dressed per hectare from 10 to 175, then 25 kg/ha steps from 175 to 200 and 50kg/ha steps from 200 to 300. As per Figure 1, (All years) refers to the 30 years from 1981 to 2010 and above and below median (AM/BM) refer to the 15 years in the sample when the rainfall from August 11 to the end of October was above or below median.

A portion of the N lost through de-nitrification is likely to be lost as nitrous oxide. Figure 4a shows that this loss is primarily driven by the rate of fertiliser. At higher rates (150 kg N/ha to 300 kg N/ha there is a strong interaction between rate and season. The large de-nitrification losses come from a small number of years as shown by the time series (Figure 4 b).

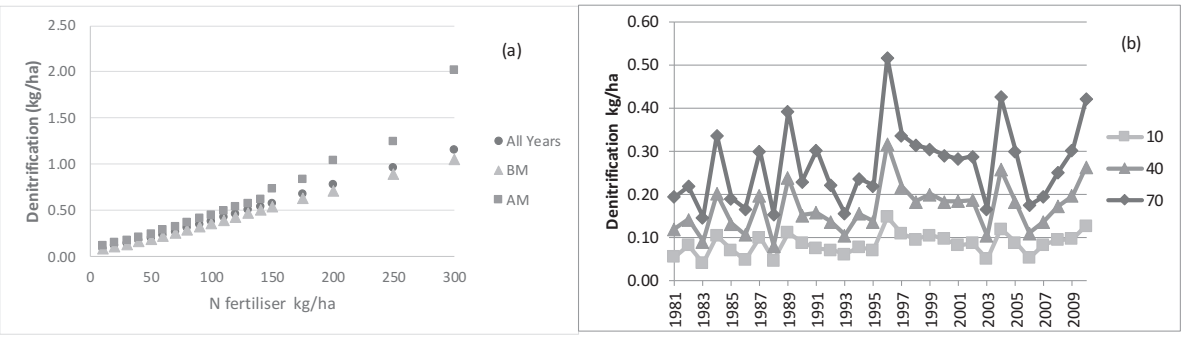

Figure 4 (a) de-nitrification losses as a response to top-dressed fertiliser averaged over 30 year period 1981 to 2010 (all years) and the 15 years with above and below median rainfall for 11 August to end of October. And (b) time series of de-nitrification losses for 10, 40 and 70 kg N/ha.

Figure 5 compares the outcome over the 30 years in term of risk as measured by the percent of times that the marginal return was less than $1.10 and return as measured by the gross margin. The lower arc of points represent fixed rates of N from zero up to 170 kg N/ha. As shown in Figure 1(b), the gross margin will increase up to 100 kg of N per hectare. Higher rates decrease the gross margin. The line running from zero to 100 kg N/ha is an efficiency frontier as the attainable points are below it, and each point on the frontier is to the left (lower risk) or above (higher return) of any other attainable point. The higher arc of points represent decision makers who are following the forecast and adjusting their N according to the rule shown in the figure.

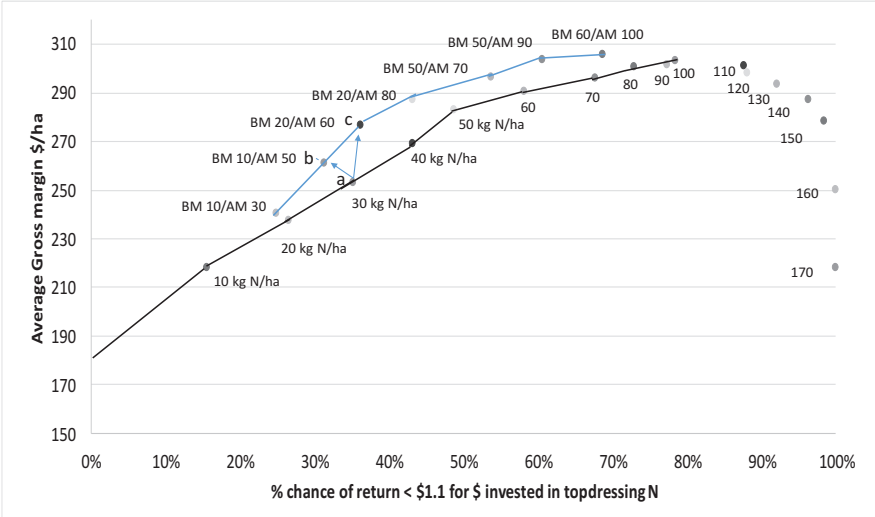

Figure 5 Risk and return of topdressing with and without a forecast. The lower arc of points are the 30-year average return from using N rates and the upper arc of points are the average risk and return from making an adjustment based on the forecast. The lines joining the points represents the efficiency frontier without the forecast (lower line) and with the forecast (upper line). The movement between points a, b and c are explained in the text below.

The main message of Figure 5 is that POAMA forecasts can shift the efficiency frontier. A farmer can change from applying 30 kg/ha every year (point a) to point (b) applying 10 kg when below median is forecast and 50 kg when above median is forecast. This leads to a gain of $8/ha and a reduction in risk (as measured by % chance of <$1.1 return) from 35% to 31%. Points (a) and (b) represent the same amount of fertiliser on average (30kg/ha). In Figure 5, 40 kg/ha is applied as 20 in below median and 60 in above median, and 50kg/ha is split 20:80. We calculated all combinations (for example 50kg/ha - 10:90, 20:80, 30:70 and 40: 60) and then selected the most efficient (highest return and lowest risk). It is interesting that at higher rates, the optimum level for below median is 50 or 60 kg N/ha. This could seem to contradict Figure 3 that shows for below median rainfall farmers should not apply more than 20 kg/ha, because the marginal return for the next step to 30 kg/ha drops below $1.10 ha. However, this logic would only hold if the forecast from POAMA was a perfect forecast. The shift from point (a) to point (c) represents the use of extra fertiliser with the forecast. This results in an increase in gross margin of $23/ha. It is important to note that some of the benefit of the "*with forecast*" case comes from the information being used to apply extra fertiliser.

Another version of Figure 5 could be drawn with the x axis as environmental risk as measured by the nitrous oxide emissions or N leaching. Under the assumptions of this simulation study, there was little change to nitrous oxide emissions or N leaching from a farmer following or ignoring POAMA forecasts. The main reason for this is that the economic optimum supply of N is below the maximum crop demand in average to good conditions.

Conclusions

Considering the marginal economic response will focus attention on the most efficient use of N. This will have the side benefit of reducing the chance of excess N increasing environmental risk.

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A simple framework for profitable fertiliser use under risk and soil constraints

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Abstract
Findings of a grower oriented research are presented, aimed at demonstrating a simple framework, with which growers can determine the fertiliser rates that maximises gross margins for wheat in Western Australia. The focus is on Economically Optimal Nutrient Rates (EONR), with emphasis on nitrogen use under different edaphic and agro-climatic conditions. Seasonal variability of price of nutrients and wheat are accounted for. Data from a decade of industry benchmarks are used to assess farmer practice in fertiliser use and the attendant yields and profits. It is shown that growers do adjust nutrient rates according to seasonal conditions and expected yields but not to the extent that may be expected when considering the large fluctuations in the price of nitrogen relative to wheat that have occurred in the last decade. Commodity statistics are used to estimate seasonal variation in the Break Even Ratio (BER) - the ratio of nutrient price to wheat price. It is shown that growers who inform themselves of yield response of their crops to a wider range of nutrient rates than those typically used, can increase their profitability by identifying EONRs that can be easily estimated using the N:Wheat price ratio, without the use of sophisticated computer models.

Key words
Wheat, nutrition, profitability, fertilizer rate, optimisation, decision support

Introduction
Fertilisers are one of the biggest cost items in the grower's annual budget (Planfarm-Bankwest 2008-2014). In the last decade the price of both Nitrogen (N) and Phosphorus (P) has varied substantially relative to price of wheat (ABARE 2013).

Yield response of wheat to N and P is usually demonstrated by a response curve that is depicted typically as a smooth, continuous curve exhibiting diminishing returns, which describes the causal relation between one or more nutrient and grain yield. Diminishing returns occurs when an additional unit of nutrient results in a less than proportionate increase in grain production (NAS 1961; Dillon 1968). Economically Optimum Nutrient Rate (EONR) is the rate of nutrient that results in a yield which maximises a crop's net return. This rate produces the Gross Margin (GM) maximizing grain yield, which is a function of grain yield, fertiliser rate and price of grain and fertiliser, among other factors. Consequently, the EONR occurs when marginal revenue (MR) from production of grain equals marginal cost (MC) of the nutrient applied. In other words, at the most profitable yield and nutrient rate, MR and MC are equal (Barnard and Nix 1976). This optimum is dependent on the price of nutrient in fertiliser relative to the price of grain, which is known as the Break Even Ratio (BER) (Sylvester-Bradley and Kindred 2009). The optimum N rate for wheat yield occurs at the point on the yield response curve where the slope of the curve equals the BER. This requires the estimation of marginal product for the nutrient (NAS 1961; Dillon 1968). Maximum financial returns for grain yield, and hence the optima for a nutrient such as N, are achieved at the rate of N where the slope of the yield response to N equals the ratio of price of N to price of wheat (Kindred *et al. 2007).*

In this paper, we acknowledge that adoption of an innovation is an economic process (Abadi et al. 2005) and thus suggest a simple method that growers can easily learn to estimate EONR prior to planting. For this method to be useful, the grower has to be aware of the yield response to the full array of N rates, from the lowest to very high rates. For simplicity, here, it is assumed that phosphate (P) use remains fixed and equal to the amount that will replace P exported by the previous crop.

Materials and Methods
Farm group statistics from industry benchmarks in Western Australia (WA) were compiled to assess recent farmer practices in fertiliser use and farm economic performance indicators for individual years for the period 2007 to 2013 (Planfarm-Bankwest 2008-2014). The single year data is ranked according to operating surplus/hectare/millimetre of growing season rainfall and grouped as top 25%, average and bottom 25%.

A sensitivity analysis was conducted using an economically optimising version of NPDecide, to determine profitable fertiliser use under different conditions. NPDecide and its various derivatives are used as decision support packages for fertiliser recommendations. The underlying model is based on an exponential wheat yield response function to N and P under different expected yields, N and P levels available in the soils and nutrient use efficiencies common in WA (Burgess *et al*. 1991; Robertson et al. 2008; Bowden *et al*. 2009). A grower can use an independent agronomist to obtain N response curves generated from a model like NPDecide or they can conduct strip trials on representative samples of soils and paddocks in different seasons, in order to understand the yield response of crops to N rates that are higher than or lower than rates typically applied. The purpose is to then use the response curve to estimate the marginal product of N use at different N rates.

The slope of the yield response curve to N at any point is the marginal product (MP) – indicating the change in wheat yield for each incremental increase in N rate. MP can then be used in conjunction with the ratio of N price to the price of wheat (Np:Wp or BER), to identify the N rate and attendant yield at which a crop is at its most profitable (EONR). The point on the response curve at which the slope equals the BER is the N rate that equals the EONR. Here we show samples of EONRs that have been estimated for wheat yield response curves to N, reflecting regional differences in expected yields and soil nutrient levels.

Results and Discussion

Current industry fertiliser use practices

Summarised farm group statistics from industry benchmarks (Planfarm-Bankwest 2008-2014) showed business performance indicators for top, average and bottom farmers in the Low Rainfall areas and Medium Rainfall areas of the WA wheat growing areas (Table 1). Data confirmed that farmers have certain ability to adjusted nutrient rates according to seasonal conditions and expected yield. For example, top farms in the medium rainfall areas varied their N use in the range of 35 to 55 kg/ha in the last seven seasons. Overall farmers adjusted nitrogen rates only by 18 to 40% around an average rate. Currently, at seeding, farmers apply that level of DAP that replaces the P for what was exported with last year's crop. Then if the weather is conducive they may apply more N with liquid fertiliser or urea once in the low and medium rainfall zones and twice if the season is above average in the high rainfall zone.

Within a rainfall area, there were substantial differences in the level of wheat yield achieved which contributed substantially to the observed differences in farm operating surplus between top and bottom farms. Soil constraints such as acidity that affect the potential attainable yield in conjunction with finance constraints, limiting the expenditure in fertilisers, play a significant role in the low farm operating surplus, especially in bottom performing farms.

Table 1. Average and coefficient of variation (cv%) of business performance indicators for a sample of grain growers for seven season from 2007 to 2013. Business performance presented as Growing Season Rainfall (GSR), Nitrogen and Phosphorus use, wheat yield, operating expenses and farm operating surplus. Data presented for top, average and bottom farms in the low and medium rainfall areas of Western Australia.

Region	Low Rainfall (L1-L4)			Medium Rainfall (M1-M4)		
Business Performance	Top	Average	Bottom	Top	Average	Bottom
GSR (mm)	195 (21%)	191 (24%)	184 (28%)	234 (21%)	230 (24%)	224 (29%)
N Use (kg/ha)	33 (40%)	27 (31%)	24 (37%)	45 (23%)	41 (18%)	37 (31%)
P Use (kg/ha)	9 (27%)	7 (21%)	7 (29%)	10 (15%)	9 (13%)	8 (25%)
Wheat Yield (t/ha)	1.9 (39%)	1.5 (37%)	1.2 (40%)	2.4 (25%)	2.0 (28%)	1.6 (37%)
Operating Expenses ($/ha)	239 (27%)	211 (24%)	191 (28%)	325 (19%)	294 (18%)	270 (22%)
Farm Operating Surplus ($/ha)	213 (49%)	110 (73%)	19 (348%)	286 (44%)	159 (60%)	45 (170%)

Wheat yield response to nitrogen and Break Even Ratio (BER)

Values of BER for the period 2000 to 2015, using actual fertiliser and wheat prices in the different years were calculated for N in the fertiliser DAP and urea, and for P in DAP and super phosphate (Table 2). If we take N in urea as example, BER values were highest in 2008 and lowest in 2015. Assuming the wheat response curve to N is known, the EONR for 2008 would be the N applied at the point where the slope of response function is 7.7 and in 2015 the point where the slope is 2.9.

Wheat response curves to N applied for high and low expected yields in the low and medium rainfall areas of WA were generated using the optimising version of NPDecide (Figure 1) taking into account assumptions of attainable yields and available N and P in the soil and nutrient use efficiencies as described in Table 3. Given the April 2015 prices of $0.89/kg for N and $0.25/kg for wheat, the BER in April 2015 would be 3.56. The EONR can be obtained as the point on each curve where the slope of the curve equals 3.56. Under the stated assumptions, the EONR for the high and low yields in the low rainfall areas would be 70 and 60 kg/ha N respectively, and for the high and low yields in the medium rainfall areas would be 42 and 34 kg/ha N respectively (Fig. 1). These N rates that maximise GMs of crops result in yields of 1840, 1260, 2310 and 1440 kg/ha respectively, all of which are lower than the corresponding attainable yields of 2300, 1650, 2650 and 1900 kg/ha. It is important to note that these yields maximise gross margin and not gross revenues, which exclude cost of nitrogen). Generally, and in particular when N:Wheat price ratio is high, to maximise GM, grower accepts lower yields and lower gross revenues than would be the case at higher N rates.

In this paper, soil constraints that affect water use and nutrient use efficiency of crops are taken into account by adjusting the expected or attainable yield. Further research will be conducted into estimating the benefit-cost analysis of expenditure in ameliorating soil constraints as well as fertiliser rates.

Table 2. Values of Break Even Ratio (BER), ratio of price of nutrients and price of wheat, for the years 2000 to 2015. Nutrients (Nut) Nitrogen (N) in fertilisers DAP and Urea, and Phosphorus (P) in DAP and superphosphate. Numbers in bold indicate the maximum value observed and the underlined numbers are the lowest values.
Notes: a: Sources: ABARE, CSBP and Profarmer; b: nominal prices; c: nutrient prices in the compound fertiliser DAP was calculated by proportioning the total cost of the compound fertiliser to each of the constituent nutrients on the basis of the cost of each nutrient (in its cheapest form e.g. from a single nutrient fertiliser like urea for N) as a fraction of the cost of all nutrients in the compound.

Nut: Fertiliser	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
N: DAP	3.3	2.7	2.7	3.5	4.0	4.4	4.3	4.4	**7.6**	5.8	5.3	6.1	3.8	3.6	4.1	3.4
N: Urea	4.7	3.5	3.3	4.4	5.8	6.0	5.3	5.2	**7.7**	6.3	5.5	7.5	4.8	4.4	5.2	2.9
P: DAP	8.7	7.3	7.1	9.2	10.5	11.6	11.5	11.8	**20.2**	15.3	14.2	16.3	10.1	9.6	10.8	9.0
P: Sup. Phos.	11.3	10.5	10.9	13.2	14.5	14.6	12.6	13.7	**22.6**	21.0	17.8	19.9	13.9	13.2	14.5	12.0

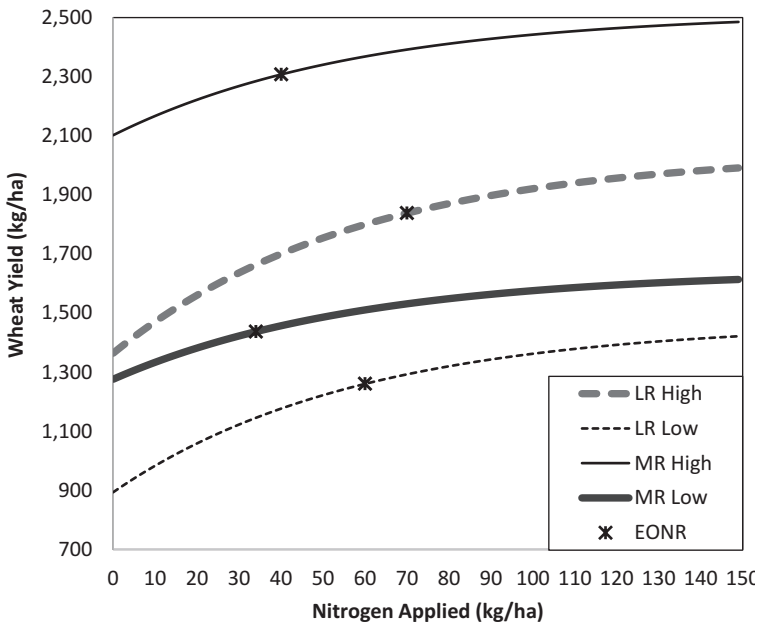

Fig 1. Wheat yield response to Nitrogen applied for High and Low expected yields in the low (LR) and medium (MR) rainfall areas of WA. Assumptions of expected yield and soil nutrient levels are shown in Table 3.

We recognise that there are constraints that may limit the extent to which grower can adjust the N rate. They include: knowledge resources of grower (access to timely, unbiased and expert advice), labour resources, financial resources, soil constraints (acidity, compaction) and diseases and pests (e.g. root nematodes) among others.

It is advisable that decisions concerning the most profitable quantity of fertiliser be made with knowledge of returns to investment in other parts of the farm business. Factors that may affect such decisions include level of equity limiting access to seasonal finance, other investment alternatives and whether the farmer is a lessee or an owner.

Table 3. Assumptions for expected (attainable) yield, available N and P in the soil and Non-fertiliser operating expenses for high and low yields in the low and medium rainfall areas. BER of 3.56 in Apr 2015. Values for soil responsiveness to added N and P are those typical of WA soils (Bill Bowden *pers comm*).

Variable	Unit	Low Rainfall GSR: 195 mm		Medium Rainfall GSR: 235 mm	
		High	Low	High	Low
Attainable Yield	kg/ha	2,300	1,650	2,650	1,900
Available N in Soil (top 10 cm)	kg/ha	55	47	90	75
Available P in Soil (top 10 cm)	kg/ha	11	11	15	10
Applied P - at seeding	kg/ha	6	6	10	8
Non-Fertiliser Operating Expenses (Opex)	$/ha	150	150	265	215
Economically Optimal N rate (EONR Apr 2015)	kg/ha	70	60	42	34
GM maximizing Yield	kg/ha	1,840	1,260	2,310	1,440
Gross Margin at EONR	$/ha	200	70	276	114

Conclusion

If a grower is aware of the current wheat yield response to a wide range of N rates on their own property, then the EONR can be easily estimated using the BER, without the use of computer models. Soil tests are necessary to provide an estimate of the soil nutrient supply and usual caveats apply about limiting factors, such as seasonal conditions, risk of dry finish and additional costs of splitting nutrient applications.

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High yielding wheat in the northern region: impact of nitrogen fertilisation on grain yield and quality in modern cultivars

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Abstract
Season to season variability in grain yields is the main factor determining farmers' conservative investment strategies in dryland cropping. Yield differences among wheat cultivars and its responsiveness to resource availability are usually related to grain number per m^2. The experience from Australia suggests that part of the low yields in dryland conditions might be due to low N availability, and that water use efficiency, yield, and grain quality could then be significantly improved by increasing N fertilizers rates. In this study, grain yield and quality were characterised for two recently released cultivars known to contrast for protein content. Crops were grown at Gatton, Queensland, under rainfed and irrigated conditions, and with three N levels. The aim of this study was to determine and quantify differences in yield and grain quality between different modern wheats grown in contrasting N and water conditions. Yield was significantly related to total dry biomass at maturity. Cultivar Suntop achieved higher biomass and yield than Spitfire beyond the treatments imposed, while Spitfire had a significantly greater percentage of grain protein than Suntop.

Key words
Triticum aestivum L, water, nitrogen, protein content, grain number, tillering.

Introduction
Yield and grain protein content are traits of primary importance for the industry (e.g. Groos et al., 2003) and can be maximised by matching canopy development to seasonal conditions through management of sowing date and density, crop configuration, nutrient supply, and varietal selection. In the northern region, water stress dominates wheat production (Chenu et al., 2011) so that greatest crop productivity involves maximising the amount of water captured by the crop while optimising its distribution between pre- and post-flowering stages. However, against the notion of managing crops to maximise water use efficiency in low rainfall environments, prevailing high nitrogen to grain price ratios require that emphasis be given to the trade-off between water use efficiency and nitrogen utilisation efficiency (Sadras and Rodriguez, 2010). Here, we discuss how water and nitrogen levels influence yield and protein content for two major newly released wheat cultivars.

Materials and methods
Growing conditions
An experiment was carried out under field conditions at Gatton Research Station (27º 33' 08.23'' S, 152º 19' 40.78'' E; altitude 91 m.) Queensland. Two wheat cultivars (Suntop and Spitfire) contrasting for grain protein content were planted on 2nd July 2014 and grown under rainfed and irrigated conditions in a split plot experiment, where the main blocks were defined by water regime and sub-blocks by cultivars and increasing levels of N supply (Table 1). Rainfed and irrigated crops received no fertilization (treatment N0), 150 kg N ha^{-1} (N150) or 300 kg N ha^{-1} (N300) at sowing (urea fertilization). Each of the six different growing conditions (Gc; Table 1) was replicated three times. All in all, there were 36 plots (six rows per plot oriented in a north-south direction). Diseases and insects were prevented or controlled by spraying recommended fungicides and insecticides at the doses suggested by their manufacturers. Weeds were removed by hand and controlled by spraying selective herbicides.

Measurements and analyses
At anthesis, a linear metre of plants was harvested and then the total number of plants and tillers counted. Within each sample, 6 plants were randomly selected as a subsample and separated in main shoot and tillers. At maturity, 2 linear metres were hand harvested, and grain yield and its main components determined. An analysis of variance and some regression analyses were performed to study the relationships between traits of interest.

Table 1. Initial conditions and treatments

Sowing date	Soil Type	Initial soil water[a] (mm)	Initial soil N[b] (kg N ha^{-1})	Plant density (plants m^{-2})	Experimental treatments: Water regime[c] (mm)	Fertilization[d] (kg N ha^{-1})	Cultivars	Gowing conditions labels (Gc)
2-Jun-14	Black Vertosol (Lawes)	206.6	70.8	150	Rainfed	0	Suntop Spitfire	Gc 1
						150	Suntop Spitfire	Gc 2
						300	Suntop Spitfire	Gc 3
					Irrigated	0	Suntop Spitfire	Gc 4
						150	Suntop Spitfire	Gc 5
						300	Suntop Spitfire	Gc 6

[a] Calculated as plant available water.
[b] Mineral N (NO_3-N + NH_4-N).
[c] Periodic drip irrigations throughout the growing season, one a fortnight to decile eight. Accumulated rainfall: 108.4 mm
[d] N as urea was applied at sowing.

Results

In this trial, the main source of variation affecting yield and most of its major determinants was N availability (Table 2). However, cultivars also differed significantly for most studied traits, and water × nitrogen interaction had an order of magnitude higher to that of the cultivar effect on grain weight.

Table 2. Means and mean square values for yield, above ground dry biomass, harvest index, protein content and main yield components.

		Yield (g m^{-2})	Biomass (g m^{-2})	Number of grains (m^{-2})	Number of grains (spike^{-1})	Number of spikes (m^{-2})	Grain weight (mg grain^{-1})	Harvest index	Protein (%)
Water regime									
Rainfed		379.0 a	939.4 a	12588.1 a	35.1 a	343.0 a	31.3 b	0.41 a	11.2 a
Irrigated		434.2 a	1032.3 a	11574.9 a	36.0 a	306.9 a	37.6 a	0.42 a	10.4 a
Cultivars									
Spitfire		365.2 b	846.3 b	10542.8 b	32.7 b	304.2 b	35.0 a	0.43 a	11.3 a
Suntop		455.3 a	1136.3 a	13680.9 a	38.5 a	345.8 a	34.0 a	0.40 b	10.2 b
Cultivar x Nitrogen									
Spitfire	N0	150.0 c	369.8 c	4099.0 c	24.7 c	165.1 c	36.6 a	0.41 b	8.5 e
	N150	461.5 b	1039.4 b	13368.7 b	36.0 b	372.2 b	34.6 ab	0.44 a	12.3 b
	N300	474.9 b	1129.5 b	14106.6 b	37.5 b	375.2 b	33.8 bc	0.42 ab	13.1 a
Suntop	N0	211.7 c	522.3 c	5895.3 c	34.1 b	170.9 c	36.6 ab	0.41 b	8.7 e
	N150	595.8 a	1467.9 a	17550.0 a	40.2 ab	436.7 a	34.2 b	0.40 b	10.4 c
	N300	523.2 ab	1333.5 a	16569.2 a	41.0 a	404.5 ab	31.6 c	0.39 a	11.5 b
Source of variation	**d.f.**								
Block (B)	2	403.0^{NS}	3812.8^{NS}	855501.7^{NS}	1.9^{NS}	718.8^{NS}	2.7^{NS}	$<0.01^{NS}$	0.2^{NS}
Water (W)	1	33591.3^{*}	104433.0^{NS}	4581418.6^{NS}	4.6^{NS}	6645.9^{NS}	310.9^{*}	$<0.01^{NS}$	2.9^{NS}
B x W	2	1741.0^{NS}	7698.0^{NS}	4735774.9^{NS}	1.2^{NS}	2227.3^{NS}	5.8^{NS}	$<0.01^{NS}$	0.3^{NS}
Cultivar (C)	1	56772.6^{***}	586760.1^{***}	66979575.0^{***}	277.2^{***}	9466.2^{*}	6.6^{NS}	$<0.01^{*}$	10.9^{***}
Nitrogen (N)	2	405847.8^{***}	2308673.7^{NS}	394469301.0^{***}	318.4^{***}	191657.9^{***}	42.8^{***}	$<0.01^{*}$	40.7^{***}
W x C	1	16186.0^{*}	102934.8^{*}	7132972.3^{NS}	11.4^{NS}	3235.1^{NS}	24.4^{*}	$<0.01^{NS}$	0.6^{NS}
W x N	2	$11664.7^{NS(c)}$	59232.6^{NS}	2091185.5^{NS}	17.0^{NS}	2339.9^{NS}	58.0^{***}	$<0.01^{NS}$	$1.6^{NS(b)}$
C x N	2	6352.6^{NS}	$62187.7^{NS(a)}$	4398658.7^{NS}	28.1^{*}	2481.4^{NS}	3.9^{NS}	$<0.01^{NS}$	3.3^{**}
W x C x N	2	24.0^{NS}	1313.1^{NS}	413510.6^{NS}	10.0^{NS}	25.8^{NS}	3.3^{NS}	$<0.01^{NS}$	0.18^{NS}
Error	19	3528.9	19135.3	3713439	7.1	1523.2	3.8	0.02	0.44

The asterisks stand for the level of significance of the mean squares: * P<0.05; **P<0.01; ***P<0.001; NS not statistically significant
[(a)]Level of significance of the mean square HxPop interaction P=0.0593. [(b)]Level of significance of the mean square WxN interaction P=0.0504
[(c)]Level of significance of the mean square WxN interaction P=0.0586

Yield was positively and significantly related to total dry biomass at maturity (r^2= 0.91; P<0.001; Fig. 1) The different cultivars and treatments resulted in a wide range of yields, which ranged from 113 to 613 g m^{-2} (oven dry; Fig. 1, left panel). The largest effect was the nitrogen availability (Table 2). The yield of the different cultivars differed significantly as well. Cultivar Suntop achieved higher biomass and yield than Spitfire in all treatments (Table 2 and Fig. 1 left panel).

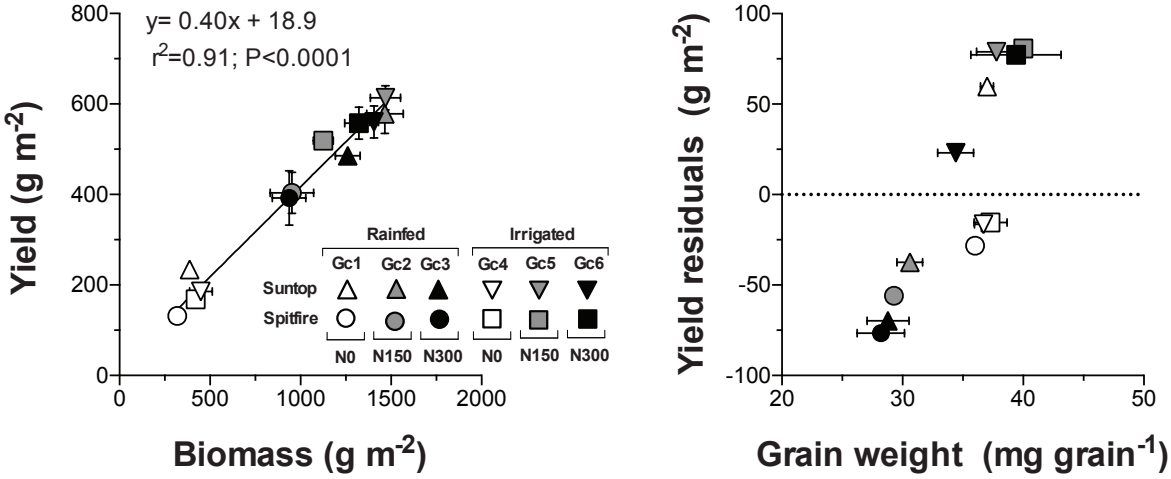

Figure 1. Relationship between yield and total biomass at maturity (left panel), and yield residuals and grain weight (right panel) during 2014 growing season, for two wheat cultivars and six growing conditions (Gc1-Gc6) at Gatton Research Station. Symbols correspond to six different growing conditions: Gc1 - Gc3: Suntop and Spitfire (triangles and circles, respectively) with 0, 150 and 300 kg N ha^{-1} (open, grey and black symbols, respectively) under rainfed conditions. Gc4- Gc6: Suntop and Spitfire (inverted triangles and squares, respectively) with 0, 150 and 300 kg N ha^{-1} (open, grey and black symbols, respectively) under irrigated conditions. Bars correspond to *SEM.*

The high yield of Suntop was correlated to a high number of grains. Suntop had more grain per m^2 than Spitfire as a result from (i) a higher spike number per m^2 as consequence of a higher tillering, and (ii) more grains per spike (Table 2). Under rainfed condition, the lower the level of fertilization the higher the grain weight, while under irrigated conditions, fertilization resulted in bigger grains (Fig. 1 right panel).

Spitfire had a significantly greater percentage of grain protein than Suntop in all fertilized conditions (Fig. 2). Significant cultivar x N interactions were also observed when N fertilisation was applied (N150 and N300) (Fig. 2 left panel and Table 2). While in most conditions, the high protein level of Spitfire was related to a relatively low yield (dilution effect), under high N (N300) and water (irrigated) availability, Spitfire achieved a high yield together with a high protein content (Fig. 2 right panel). By contrast, the yield of Suntop was reduced by the highest fertilisation level (N300) compared to a more moderate level (N150) in both the rainfed and the irrigated treatments.

In the case of unfertilized treatments (values within dotted circle in Fig. 2, right panel) there was a strong yield reduction as a consequence of a severe N stress (Fig. 2 right panel).

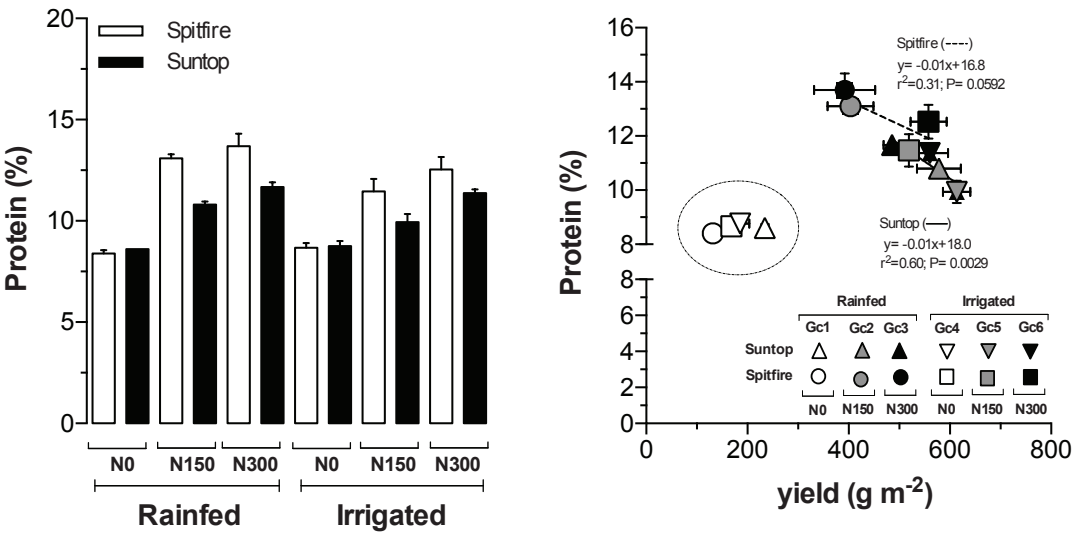

Figure 2. Left panel: grain protein content under different N fertilization (0, 150 and 300 kg N ha^{-1}) and water availability for Spitfire and Suntop in 2014 at Gatton. Right panel: relationship between grain protein content and yield. Bars correspond to *SEM.*

Discussion

Significant differences were observed when we compared grain yield and protein content of Spitfire and Suntop. The main differences between these two wheat cultivars were related to biomass production, yield and grain protein content. The fact that genotypic differences in yield were closely related to their biomass highlights that it is likely to improve yield through increasing biomass rather than its partitioning This was in line with what Ferrante et al. (2012) found when they subjected wheat to different N and water availabilities. This is, in turn, rather relevant as further gains in harvest index are limited (though still possible; Foulkes et al., 2011).

Results also provide evidence of the benefit from properly targeting levels of nitrogen supply to seasonal conditions and expected yields (e.g. over fertilization of Suntop resulted in reduced yield). In addition, there was a trade-off between being efficient for producing yield and for having high grain protein percentage.

In conclusion, the results of this comparison of wheat cultivars provide empiric evidence of the advantage to get more grains, and produce more biomass to increase yield potential.

Acknowledgements

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Profit and risk in dryland cropping: seasonal forecasts and fertiliser management

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Abstract
Fertiliser management in dryland cropping involves a trade-off between risk and return. Increasing the fertiliser application rate can increase profit in good years, but may lead to a loss in bad years. Farmers try to avoid the potentially serious consequences of consecutive loss years by adopting a conservative strategy, typically applying $1 of fertiliser only when the long-term net return would be $2. A forecast of seasonal rainfall can help inform fertiliser management decisions; application rates can be increased in forecast good years and decreased in forecast bad years. The value of a seasonal forecast of above/below median rainfall was determined at a variety of sites in the Australian wheat belt. The long-term value of the forecast varied from $16/ha to $80/ha, compared to a realistic conservative strategy without a forecast. This value was achieved with little increased risk. The same value could be obtained by increasing fertiliser rates in every year, but the risk was higher. Seasonal forecasts give probabilistic information about the seasonal bias and are therefore valuable in the long-run rather than in any given year. At the sites studied, and at an 80% level of surety, seasonal forecast information was of value over time periods ranging from three to eight years.

Key words
Risk-averse nitrogen management, variable climate

Introduction

The application of nitrogen fertiliser in dryland cropping requires a balance between risk and return. The optimum fertiliser rate will vary from year to year depending on seasonal rainfall. Too much fertiliser in a dry year can lose money, while too little fertiliser in a wet year is a lost opportunity. Forecasts of seasonal rainfall are now sufficiently skilful that they can be of considerable value when benefits are averaged over a number of years. In the southern part of the Western Australian wheat belt, it has been shown that even moderately skilful seasonal forecasts of rainfall can have a value exceeding A$50 /ha when averaged over 27 years (Asseng et al., 2012). This value exceeds that of previous studies (e.g. Ash et al., 2007; McIntosh et al., 2007; Moeller et al., 2008; Wang et al., 2008) because of the use of a realistic and conservative baseline management strategy in the absence of a forecast.

Seasonal forecasts are, by necessity, probabilistic rather than deterministic, regardless of the method used. It is not possible to give definitive predictions at seasonal timescales because of the chaotic behavior of the climate system. However, it is possible to make probabilistic statements about the chances of rainfall in the coming season. The simplest format is to specify whether the rainfall is likely to be above or below the long-term median value. The use of probabilistic information is not familiar to many people, and there can be a tendency to reject a forecast system if the most likely outcome does not eventuate when it is first used. However, the value of a probabilistic forecast system lies in the longer term, and it is important to communicate this fact clearly.

This work had two goals. The first was to demonstrate that the excellent results achieved by Asseng et al. (2012) in Western Australia are likely to be achievable in the eastern wheat-belt of Australia as well. The second goal was to start to explore the number of years a forecast should be used in order to be reasonably certain (at some level of probability) that it adds value.

Methods

The methods used here closely follow those used by Asseng et al. (2012) in Western Australia. The experiments were designed to explore the value of climate forecasts in the absence of other factors, such

as carryover from year-to-year of nitrogen and stored soil water, disease, pest, frost, heat stress and crop rotation. It will be desirable in future studies to extend the realism of the simulation and explore non-linear interactions by incorporating some or all of these additional factors.

There were four study sites in New South Wales (NSW) spanning low to moderate rainfall regimes for the May-Nov growing season: Griffith (245 mm), Ardlethan (292 mm), Temora (329 mm) and Young (421 mm). A continuous wheat system on red Chromosol soil was simulated using APSIM Wheat version 7.5 (Holzworth et al., 2014). The cultivar "Scout" was sown according to a variable sowing rule: when 30 mm total rain fell in 10 consecutive days between 15 April and 10 July, or on 10 July if there was insufficient rain. Soil water was reset to the lower limit and nitrogen reset to 50 kg N/ha on 15 April.

Nitrogen fertiliser was applied at a rate determined by a range of profit ratios from $0 to $3 per $1 of fertiliser applied. A profit ratio of $0 means that the fertiliser rate is determined from the maximum of the gross margin (GM) versus N curve from past years. A profit ratio of $3 is determined from where the GM versus N curve has a slope of 3:1, and will generally result in a much smaller application of N. Farmers in Western Australia indicated that they generally operated at a profit ratio of $2-3 (Asseng et al., 2012) so as to reduce the risk of losing money in a dry year.

Forecasts of May to November rainfall made on 1 May were obtained from the Australian Bureau of Meteorology's Predictive Ocean-Atmosphere Model for Australia (POAMA). This model is a dynamical global coupled ocean-atmosphere-land computer model initialized at each forecast start time from a vast network of atmosphere and ocean observations (e.g. Hudson et al., 2013; Zhao et al., 2014). The model provides retrospective forecasts extending back to 1981. While POAMA provides multiple forecasts to explore the spread of possible outcomes, we simply used the mean rainfall at each site and compared this to the model's long-term mean rainfall there. At the four sites in NSW, POAMA correctly predicted whether rainfall would be above or below the median between 74% and 81% of the time.

If the forecast in a particular year was for above median rainfall, then the GM versus N curve from which the fertiliser rate was determined was constructed from all historical years where the rainfall was observed to be above the median. The below median case was treated similarly. In experiments where no forecast was required, all historical years back to 1981 were used. Example curves for Nyabing are shown in Figure 1; the other sites are qualitatively similar. See Asseng et al. (2012) for further details about the method.

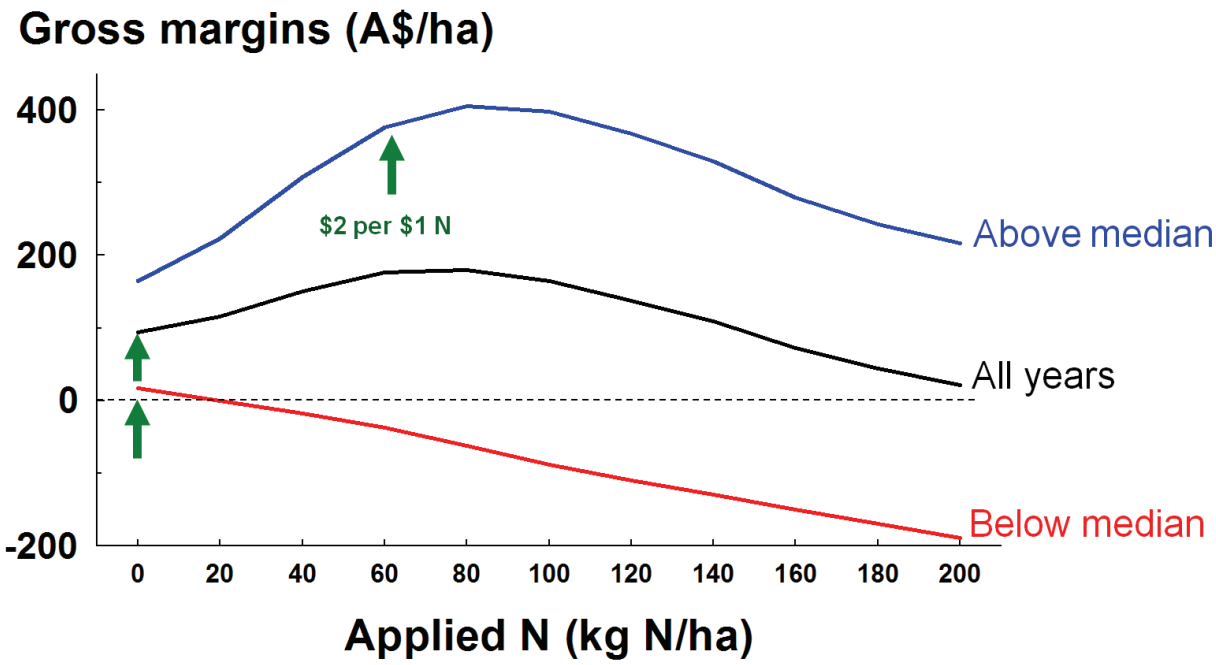

Figure 1. Gross margin versus N fertiliser application for all years (black), above median rainfall years (blue) and below median rainfall years (red) at Nyabing, WA. The N rate appropriate to a profit ratio of $2 for each $1 applied N is indicated by the green arrows. The other sites are qualitatively similar.

The "break-even time" is the number of years a farmer would need to grow a crop in order to be, say, 95% sure that the farm is not losing money. The break-even time can then be compared between experiments using different profit ratios, or between experiments with and without a forecast. Figure 2 shows the 5th and 95th percentiles of gross margin for all combinations of modelled years taken n at a time, where n is the number of years along the x-axis. For example, at Nyabing, where there were 27 years modelled, there are many subsamples of length 10 years. The statistical distribution of the set of subsample means provides the percentiles when n=10.

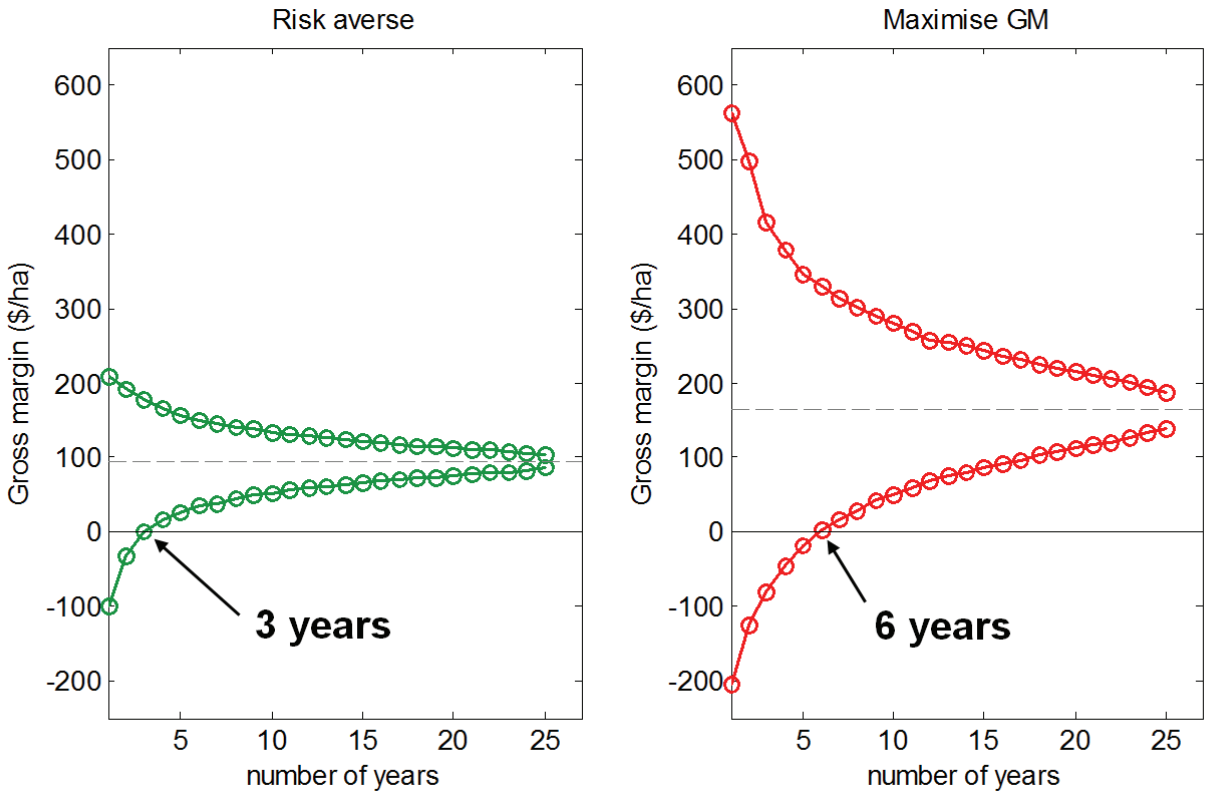

Figure 2. Gross margin 5th and 95th percentiles over varying numbers of years (subsample sizes) for a profit ratio of $2 (green) and profit ratio $0 (red). These results are for Nyabing, WA. The break-even time is indicated where the 5th percentile becomes positive.

Results

We compared the original Western Australian site (Nyabing) with preliminary modeling at the four eastern Australian sites. Further refinement of starting soil moisture and the sowing rule will be necessary to fully account for the differences between conditions in the east and west. However, these initial experiments have shown encouraging gains from a seasonal forecast. At a $2 profit ratio, using a forecast increased the long-term profit at all sites between $16 /ha (Griffith) and $80 /ha (Ardlethan). The original value at Nyabing (on a clay soil) was $65 ha. It is clear that the good results obtained in WA by Asseng et al. (2012) will be feasible in eastern Australia.

There are various possible risk metrics for dryland cropping, such as the percentage of loss years, the mean long-term loss, the chance of two loss years in a row, and the number of years to break even. Using a forecast increased all these risks at Nyabing, and increased the mean loss at Temora. All other risks remained the same or decreased. This must be compared with the alternative strategy for obtaining the same profit; decreasing the profit ratio and effectively applying more N in each year regardless of the forecast. This amounts to moving the green arrow to the right along the black curve in Figure 1 until the profit equals that obtained using a forecast. In this case, out of the four risks mentioned and over the five sites, the risk increased in 15 out of these 20 cases compared to using a forecast, and otherwise remained the same.

A forecast adds value when the 5th percentile using a forecast exceeds the 5th percentile when a forecast is not used. It may take a number of years for this to occur. This is a generalisation of comparing break-even times. The number of years taken for a forecast to be of value (at the 80% level) was estimated this way at each site.

Future calculations will use a more robust bootstrapping method. A forecast was found to be of value after between three and eight years at all sites. This calculation assumes the climate in each year is uncorrelated with neighbouring years. If correlation between years is allowed for, the calculation is only approximate due to the short time sequence available, but the indication is that this time increases by one to three years.

Conclusions

There is a trade-off between risk and return in dryland cropping because of Australia's variable climate. Applying more fertiliser each year increased the long-term return, but at an increased risk. By comparison, strategic application of more fertiliser based on a seasonal climate forecast increased the return at reduced risk. A seasonal forecast was found to be of value after three to eight years at the sites studied, and the return was between $16 /ha and $80 /ha, indicating the great potential value of seasonal forecasts. Extension of this work in future studies might take a whole-of-system approach and incorporate additional factors such as knowledge of stored soil moisture at planting.

Acknowledgement

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Nitrogen Management: do barley varieties respond differently to Nitrogen?

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Abstract

In the Victorian Wimmera and Mallee many different barley varieties are grown in an attempt to meet malting markets. The use of in-crop nitrogen (N) is always at the forefront of grower's minds to ensure that malt specifications are met and that there is at least a 2:1 return on the investment of N. An experiment was set up in 2013 at Nhill in the West Wimmera of Victoria, on a low N site, to determine if new and existing barley varieties respond differently to varied N rates applied at sowing and in-crop. Barley varieties have different growth habits, which potentially impacts the way they respond to N. New Varieties are always being released and there is very little understanding about how these varieties should be managed.

In the trial, highest yielding varieties were Commander, La Trobe and Hindmarsh. Despite the varying rates of N applied, in a year with a wetter than average growing season rainfall, all barley varieties had a similar yield response to N. The greatest profitability in 2013 was achieved with 120kg N/ha applied to barley at Nhill. Even though barley varieties differ in their growth habit, none of the varieties responded differently to each other in terms of yield, test weight, screenings and retention.

Key words

Barley varieties, nitrogen response, interaction, nitrogen, management, barley agronomy

Introduction

This trial was conducted in 2013 as part of the state tri-funded GRDC barley agronomy project, determining whether new and current barley varieties respond differently to nitrogen (N). A variety that is more 'nitrogen' efficient than another, can achieve a greater yield on the same N supply (assuming everything else is equal). Varieties differ in their sensitivity to management practices consequently not all barley varieties can be treated as equal and in some circumstances should be managed differently.

Hindmarsh and La Trobe both have a semi-dwarf gene which causes an erect leaf habit and slower early growth.. Nitrogen responsive varieties such as Hindmarsh benefit from earlier applications of N. (Porker. K, 2014). This paper investigates whether barley varieties respond differently to N applications and whether growers should be implementing N management packages tailored to each variety to ensure they reach their full potential.

Methods

The trial was established at Nhill in the western Wimmera region of Victoria on a Wimmera grey, cracking clay. Rainfall distribution is Mediterranean and the site received 339mm (decile 8) of growing season rainfall. The pre-sowing mineral N status of the trial site was very low at 28kg N/ha to 100cm (nitrate and ammonium nitrogen) after being sown to oaten hay the previous year. The trial was sown on 23 April 2013 at a target plant density of 130 plants/m^2. Varieties sown included Hindmarsh, Skipper, Westminster, Scope CL, La Trobe, GrangeR, Commander and Flinders. All N treatments were applied as urea (46% N) and broadcast using a hand held garden spreader prior to planting and incorporated into the soil by the seeder (Table 1). Though the site received 15mm of rainfall two days prior to sowing, topsoil conditions were marginal for emergence and despite moisture at depth, emergence did not occur until late May. The 120 and 240kg N/ha treatments received a second application of N at early tillering (GS15/21 on 11 July) (Table 1). All treatments received sufficient rainfall after each application to ensure N was washed into the soil. Waterlogging occurred during July and early August (all urea was applied before the water logging occurred), during which time accessibility to the site was limited. However, there was no known impact on plant growth or end yield across the waterlogged site. Measurements included emergence counts (GS23), NDVI (Normalised Difference Vegetative Index) at GS65 and GS85, head counts, yield and grain quality. Partial' gross income (yield t/ha x grain price – N cost) was determined after classifying individual plots as Malt or Feed, based

on quality parameters. Cash prices used were from Nhill GrainCorp; CO1 $211/t, HIND $206/t, F1 $285/t, F2 $172/t (taken on 27 November 2013) to establish returns. Prices were Plots were harvested with a Wintersteiger plot harvester and protein was measured using a Foss Infratec NIR whole grain analyser. Yields were corrected to 11.5% moisture. All other quality parameters (retention, test weight and screenings) were measured with standard procedures.

Table 1. Amount of nitrogen per treatments applied prior to sowing and at early tillering (GS15/21)

Treatment	Applied N (kg/ha)		Total N (kg N/ha)	Total Urea (kg/ha)
	Sowing (23/4/13)	Early tillering (11/7/13)		
A	0	0	0	0
B	30	0	30	65
C	60	0	60	130
D	90	30	120	260
E	120	120	240	522

Results

The low initial soil N status combined with above average growing season rainfall, meant the crop was responsive to N. The trial emerged on 29 May following rainfall on 23 May. Four weeks after sowing, plants in the high N plots (120 and 240kg N/ha), were at growth stage GS11-12, whereas plants in the low N plots were not as developed (GS05). Plant counts were also conducted at the mid tillering stage, showing that the low N plots had tillered less than the higher N plots, but there were no significant differences in plant numbers.

Was there a difference between nitrogen rates?

When applying higher rates of N, there were differences in yield, protein, test weight, retention and NDVI, but no differences in head counts and screenings (<7%). Assessments at GS65 showed NDVI increased as applied N increased. This was due to a greater amount of 'canopy greenness' and biomass production with increasing N rates. A similar trend was noted at GS85, but NDVI values were much lower as the crop was senescing (at grain filling stage).
As expected, applying a greater amount of N resulted in a higher yield (Table 2). The highest mean yield of 4.8t/ha was achieved at the highest rate of 240kg N/ha.

Table 2. Grain yield and quality with applied urea rates.

Total Nitrogen applied (kg N/ha)	Grain yield (t/ha)	Grain protein (%)	Test Weight (kg/hL)	NDVI GS65
0	1.7	10.8	60	0.44
30	2.4	9.9	61	0.58
60	3.2	9.7	64	0.69
90	4.1	10.6	67	0.79
240	4.8	12.8	69	0.85
lsd (P<0.05)	0.2	0.3	2	0.03

Figure 1 shows the relationship between yield and partial gross margin with increasing N rate. While the highest yield occurred at the 240kg N/ha rate, the greatest yield response was seen at the 120kg N/ha rate (as response starts to ease when applying a higher rate). Consequently, partial gross income was greatest also when applying 120kg N/ha. This indicates, that aside from the highest yield being achieved at the 240kg N/ha rate, it was more profitable to apply 120kg N/ha (highest partial gross margin) as there was not sufficient yield benefit to warrant adding extra N.

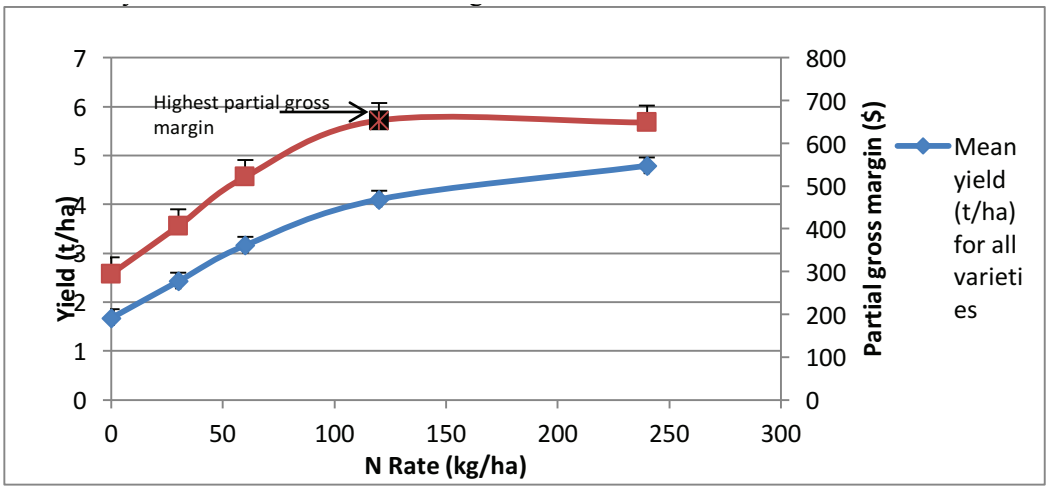

Figure: 1 Relationship between Yield (t/ha) and partial gross margin ($) when applying N
(Significant difference, Rate (Yield) P<.001 LSD=0.18 CV%11.2, Rate (partial gross margin) P<0.001 LSD=39.7 CV%15.9)

Did varieties respond differently?
Despite there being a positive response to applied N, no variety responded significantly differently from another in terms of yield, test weight, screenings and retention. For example, when applying 60kg N/ha to Hindmarsh, the response in yield was similar for all varieties at that rate. There were significant interactions in protein content between varieties and N rate. Among the malting varieties, GrangeR at 60kg N/ha had higher protein (9.4%) than Commander (8.2%), which inheritantly has a lower protein, similar to Gairdner (Table 3). Economic comparisons between varieties showed the partial gross margin of each variety increased with higher rates of N (Table 3). The most profitable rate of N across most varieties was achieved at the 120kg N/ha rate (260kg/ha urea).

Table 3. Summary of varieties x N rate for yield and grain quality, 'partial' gross margin and return on investment ($). Bolded values indicate the highest gross margin value. Note: the cost of N was the only cost incurred in this partial gross margin.

Variety	N Rate (kg N/ha)	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Income ($/ha)	Cost of Urea ($/ha)	Partial gross margin ($/ha)
Hindmarsh (Food)	0	2.0	10.3	60.9	342	0	348
	30	2.5	9.5	64.6	474	34	444
	60	3.4	9.5	65.5	658	68	591
	120	**4.6**	**10.7**	**69.1**	**952**	**136**	**818**
	240	5.1	13	69.8	1015	271	745
Skipper (Feed)	0	1.8	10.7	59.3	322	0	323
	30	2.5	9.8	60.8	438	34	403
	60	3.3	9.9	64.6	595	68	525
	120	**4.1**	**10.6**	**65.9**	**767**	**136**	**630**
	240	4.7	13	66.5	871	271	597
Westminster (Feed)	0	1.5	10.2	65.2	272	0	272
	30	1.9	11	58.2	341	34	306
	60	2.5	10.7	60.4	439	68	371
	120	3.2	11.5	62.9	572	136	435
	240	**4.3**	**12.6**	**69.3**	**796**	**271**	**523**
Scope CL (Malt)	0	1.6	11.3	58.1	288	0	288
	30	2.6	10.3	58.5	460	34	426
	60	3.0	10	61.6	553	68	481
	120	**3.9**	**10.6**	**64.6**	**743**	**136**	**607**
	240	4.5	12.6	64.9	841	271	569
La Trobe (Feed)*	0	1.9	10.1	58.8	331	0	331
	30	2.7	9	63.2	490	34	453
	60	3.6	9.1	67.1	666	68	597
	120	4.4	9.6	68.7	819	136	680
	240	**5.7**	**12.1**	**69.6**	**1047**	**271**	**774**

GrangeR (Malt)	0	1.5	11.1	58.2	266	0	265
	30	2.4	9.8	56.6	437	34	403
	60	3.2	9.4	61.4	559	68	489
	120	4.0	11	65.6	738	136	600
	240	**4.6**	**13.7**	**68.3**	**906**	**271**	**639**
Commander (Malt)	0	1.7	10.3	56.9	306	0	305
	30	2.8	8.8	61	509	34	475
	60	3.8	8.2	66.1	774	68	704
	120	**4.7**	**9.4**	**68.5**	**985**	**136**	**849**
	240	5.1	12	69.8	1078	271	805
Flinders (Feed)	0	1.2	12.1	58.9	222	0	223
	30	2.1	11.3	61.1	375	34	340
	60	2.7	10.8	63.0	486	68	417
	120	**4.1**	**11.5**	**68.6**	**753**	**136**	**615**
	240	4.4	13.4	69.9	816	271	542
Lsd (P<0.05)		0.2	0.42	2.32			
Variety							
Nitrogen		0.2	0.3	1.8			
Variety x Nitrogen		NS	0.9	NS			

Note: **Prices for malt, were based on Commander price only, as no prices for GrangeR and Scope CL were available at the time. All feed varieties listed are undergoing malt accreditation.
*At the time of writing this article La Trobe was a feed variety, it has since been classified as Malt.

Conclusion

In 2013, all varieties had a similar yield response to the application of different N rates. High N input costs can be potentially risky, particularly in the event of a dry finish to the season. Fortunately, due to the exceptional amount of growing season rainfall experienced at Nhill, this was not the case and yields were greatest when applying high N rates. Corresponding to this, higher N rates were also the most profitable, with the best rate of N to apply being 120kg N/ha to achieve the highest gross margin. Each variety (except Commander), achieved adequate N to achieve Malt at the lower rates of N (0, 30 and 60kg N/ha rates). When the highest rate of N (240kg N/ha) was applied, the maximum protein level for Malt (12%) was exceeded when the yield potential was met. In a high rainfall and high yielding area, Commander, La Trobe and Hindmarsh achieved the greatest yields and were the most profitable. The choice between growing Hindmarsh and La Trobe or Commander, largely comes down to the price differential between Malt and Food/Feed barley. With this in mind, select a barley variety that is best suited to your farm (in terms of soil type, rotational history, rainfall, environment and market availability). Given the variability in seasons, gaining a better understanding of soil N prior to sowing, the amount of N required to achieve maximum yield potential and timing of N applications, will contribute to better crop management and increased yields and profit.

Acknowledgements

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Effect of water availability and nitrogen source on wheat growth and nitrogen-use efficiency

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Abstract
Soil moisture content has a significant impact on soil nutrient availability. Excessive soil moisture due to waterlogging can severely reduce nutrient availability through denitrification, leaching and restricted root growth, which impairs nutrient uptake by plants. This reduces nitrogen (N) uptake and utilization by plants thereby decreasing nitrogen-use efficiency (NUE). Controlled-release fertilizers (CRFs) can improve NUE through synchronisation between N supply and crop demand. A study was conducted to investigate whether timing of N application and source of applied N can alleviate the adverse effects of waterlogging on wheat growth and improve NUE. A split-plot design experiment with irrigation regime as main-plot factor and nitrogen application sub-plot factor was setup. Irrigation regimes included waterlogged and rainfed; nitrogen treatments included: nil N, single-and split-applied urea and CRF. Wheat growth and yield attributes were monitored during stem elongation and anthesis. Grain yield and NUE were determined at harvest. The study findings showed that waterlogging significantly ($P<0.05$) decreased tiller number, ear number and NUE for all nitrogen treatments. Although split-applied urea had a higher number of tillers and ears than single-applied urea under waterlogged conditions at harvest, there was no significant yield advantage under both irrigation regimes. The CRF increased grain yield by 1t/ha compared to both single- and split- applied urea of the waterlogged treatment. CRF also improved wheat NUE by 7% and 10% under rainfed and waterlogged conditions respectively.

Key words
Triticum aestivum; duplex soil; enhanced-efficiency fertilizers; yield components; nitrogen fertilizer and high rainfall zone.

Introduction

Water availability plays a significant role in crop growth development; however, excessive soil moisture content has detrimental effects. In Tasmania an estimated 23% of the soils are duplex and susceptible to waterlogging (Cotching et al. 2009), causing wheat grain yield losses of *c*. 30-50% (Zhou 2010). These yield losses are usually as a result of reduced tiller and grain number, restricted root growth, reduced dry matter accumulation, premature leaf senescence and production of sterile florets.

Nitrogen (N) fertilizer application is said to play a significant role in improving plant growth and development under waterlogged conditions. Various studies have shown that N, applied as foliar sprays or top-dressed, can increase grain yield by around 20% through a combination of root and shoot growth including plant height, tiller number and spikelet number (Pang et al. 2007; Robertson et al. 2009; Swarup & Sharma 1993). Nonetheless, conventional N fertilizers are easily lost through leaching, denitrification, immobilization, volatilization and surface runoff during waterlogging (Mathers et al. 2007), which reduces nitrogen-use efficiency (NUE). With the increasing environmental and health concerns associated with N fertilizer use in agriculture there is need to maximise NUE. Timing of N application influences N loss and split N application is often recommended over single N application. Controlled-release fertilizers (CRFs) often referred to as enhanced-efficiency fertilizers have also been reported to be a viable option for improving NUE through synchronisation between N supply and crop demand (Chen et al. 2008). However, most work under waterlogged conditions has focused on the conventional N sources such as urea with no deliberate intention to explore the potential of CRFs. Also, attempts to evaluate the potential of N fertilizer application in reducing the adverse effects of waterlogging under field conditions have received little attention. This study investigates whether timing of N application and source of applied N can alleviate the adverse effects of waterlogging on wheat growth and improve NUE.

Materials and methods

The study was conducted at Cressy Research and Demonstration Station 45km south of Launceston. The site is located $41^0$72'S, $147^0$08'E and 150m above sea level. The site soil is duplex in nature posing significant problems to agricultural use. The area receives an average annual rainfall of 626mm; making it one of the high rainfall zones (HRZs) in Australia. A split-plot design with irrigation regime (waterlogged and rainfed) and N application (nil N, single-applied urea, split-applied urea and CRF) as the main-plot and subplot factors with three replications was used. Waterlogging was instigated at tillering (GS20) for 28 days using a drip irrigation system setup to ensure the water level is kept above the soil surface. Nitrogen fertilizer was applied at a rate of 90kg/ha; urea (46-0-0) and CRF (39-0-0) were used. Single-applied urea and CRF had full amounts applied once at sowing while split-applied urea had 40% applied at sowing and the remaining 60% top-dressed at GS32 after waterlogging.

Wheat (*Triticum aestivum*) cv. Revenue dressed with fungicide "Real" (Triticonazole and Cypermethrin) was sown early June 2014. The crop was drilled at a depth of 30mm at a seed rate of 125kg/ha with a 150mm row spacing in plots 8m long and 1.8m wide. The rainfed block was formed into 12 raised beds using a commercial bed former with a depth of 300mm and a furrow width of 300mm. The waterlogged block consisted of 12 flat (unbedded) plots. At sowing, a starter fertilizer with no nitrogen (N: P: K: S: Ca; 0-6-17-7-13) was applied at a rate of 250kg/ha. During waterlogging, the raise in the depth of the water table was monitored using small diameter (50mm) PVC tubes (piezometers) installed to a depth of 1m. Three piezometer tubes were randomly installed in the rainfed and waterlogged blocks at 6m spacing. The depth of the water table was recorded manually using a sampler and tape measure.

Plants were monitored for specific growth stages (Zadoks et al. 1974). At stem elongation (GS32) plants within a $0.3m^2$ quadrat were hand harvested, 12 plants were randomly selected and processed for tiller number, green leaf area and total above ground dry matter (AGDM). At harvest, plants within a $0.3m^2$ quadrat were hand harvested and processed for tiller number and ear number. The ears were dried, threshed and grains weighed for grain yield. NUE was calculated as a ratio of grain yield to N supply. Nitrogen supply in this study refers to the amount of mineral fertilizer applied. Data was analysed using two-way ANOVA to determine treatment interactions using GenStat 17th edition. Treatment means were deemed significant at 5% LSD.

Results

The depth of the water table varied from 140 to 200mm during waterlogging; it was maintained in the top 300mm of the rhizophere (Figure 1). The rainfed treatment which received at total of 351mm of rainfall during the experimental period (BOM 2015) had its depth of the water table vary from 580 to 880mm.
At GS32, there was a significant interaction between irrigation regime and N fertilizer application for tiller number ($P = 0.019$), leaf area ($P = 0.044$) and total AGDM ($P = 0.041$). Waterlogging significantly decreased tiller number, leaf area and total AGDM for all nitrogen treatments in comparison with the rainfed treatments (Table 1). No significant differences were observed between N treatments for all parameters measured under waterlogged conditions. However, under rainfed conditions, significant differences were noted with CRF being greater than the control (nil N) for tiller number (9.1 cf 5.1), leaf area (321 cf $115cm^2$) and total AGDM (2.6 cf 1.5g). No significant differences were observed between CRF and conventional urea treatments for all measured parameters.

At harvest, significant differences ($P<0.05$) in irrigation regimes were marked with low tiller number, ear number and NUE for the waterlogged plants (Table 2). Nitrogen fertilizer application however, improved tiller number, ear number, grain yield and NUE of the waterlogged plants (Table 2). The CRF increased grain yield by 1t/ha compared to both single- and split- applied urea of the waterlogged and improved wheat NUE by 7% and 10% under rainfed and waterlogged conditions respectively.

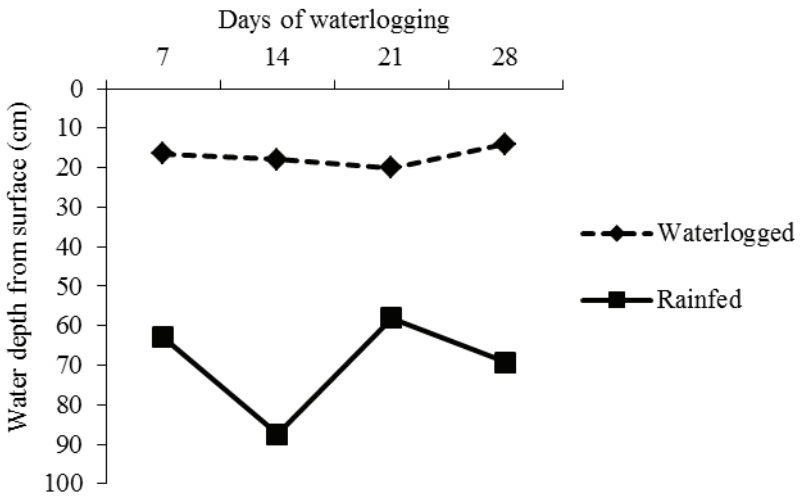

Figure 1. Level of the water depth from the surface during waterlogging.

Table 1. Growth attributes at stem elongation under different irrigation regimes and nitrogen levels.

GS32	Irrigation regime	Nitrogen level	Parameter		
	Rainfed		Av tiller number / plant	Av leaf area/plant (cm^2)	Av AGDM/plant (g)
		Nil N	5.1a	115ab	1.5b
		Single-applied urea	8.0b	241bc	2.4c
		Split-applied urea	7.8b	234bc	2.3bc
		CRF	9.1b	321c	2.6c
	Waterlogged				
		Nil N	3.8a	4a	0.4a
		Single-applied urea	4.2a	13a	0.6a
		Split-applied urea	3.9a	11a	0.5a
		CRF	4.4a	22a	0.6a

*Treatments followed by the same letter are not significantly different (*P*>0.05).

Table 2. Growth and yield attributes at harvest under different irrigation regimes and nitrogen levels.

GS91	Irrigation regime	Nitrogen level	Parameter			
	Rainfed		Tiller number/ m^2	Ear number/m^2	Grain yield (t/ha)	NUE (g/g)
		Nil N	604cd	492bc	3.8ab	-
		Single-applied urea	692d	686d	7.7bcd	85.3ab
		Split-applied urea	647d	627cd	7.8cd	87.2ab
		CRF	657d	632cd	9.2d	102.7b
	Waterlogged					
		Nil N	280a	272a	3.6a	-
		Single-applied urea	351ab	336ab	5.6abc	61.7a
		Split-applied urea	424abc	403ab	4.9abc	55.2a
		CRF	526bcd	477bc	6.8abc	75.0ab

*Treatments followed by the same letter are not significantly different (*P*>0.05).

Discussion

Waterlogging adversely affected wheat growth and development. The low tiller number, ear number, leaf area and total AGDM of the waterlogged plants could be attributed to the decreased availability of essential plant nutrients leaving plants with marked nutritional deficiency symptoms. Waterlogging also decreases root biomass through root death, which impairs the ability of plants to forage for the already limited resources (Pang et al. 2007). The low AGDM and grain yield is possibly due to premature leaf senescence, reduced tiller and grain number and production of sterile florets. On the other hand, N fertilizer application improved wheat performance under rainfed and waterlogged conditions. Nitrogen is a vital macronutrient for plant

growth with 75% of the total leaf N allocated to the chloroplasts for synthesis of components for the photosynthetic apparatus particularly RuBisCo, that plays a significant role in CO_2 assimilation (Hirel et al. 2007). The improvement in leaf area, tiller number, ear number, grain yield and AGDM under both irrigation regimes may be due to increased N uptake, which increases leaf chlorophyll content and photosynthetic capacity. This propels vegetative growth (tillering and canopy size and duration), resultant grain yield and biomass. The role of N availability particularly in the form of NO_3^- ions in alleviating the consequences of waterlogging was emphasised by Drew (1991); NO_3^- ions can replace molecular O_2 as a terminal acceptor thereby sustaining respiration and cell survival during anoxia through dissimilatory NO_3^- reduction. However, the efficiency of N fertilizer application is usually reduced by waterlogging when significant amounts are lost through volatilization, denitrification and leaching. This might be responsible for the low tiller and ear numbers, grain yield and NUE of waterlogged N fertilizer treatments. The higher growth and yield attributes, and NUE for CRF than single-and split-applied urea for both irrigation regimes can be related to it's ability to synchronise N release with crop demand (Chen et al. 2008).

Conclusions

Although waterlogging is still a major abiotic constraint to wheat production, N fertilizer application could improve wheat yield. The timing of N application and source are important. Applying full amount of the required fertilizer at sowing helps plants to withstand the adverse effects of transient and intermittent waterlogging through enhanced vegetative growth.Using CRFs may improve wheat growth and NUE under rainfed and waterlogged conditions though there might be no significant yield advantange over conventional urea to warrant investment. Nonetheless, there is need to evaluate different CRF products available for their potential in broadacre cropping and understand the processes involved in improving NUE and how they can be enhanced to maximise their productivity.

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"On-demand" hardseeded pasture legumes – a paradigm shift in crop-pasture rotations for southern Australian mixed farming systems

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Abstract
This paper presents a synopsis on the past 10 years of hardseeded annual legume research and adoption. Failure of traditional legume species such as subterranean clover (*Trifolium subterraneum*) and annual medics (*Medicago* spp.) in the medium and low rainfall zones of NSW and WA necessitated the development of crop-pasture rotation systems underpinned by more resilient legume species. Such species had been developed and included biserrula (*Biserrula pelecinus*), bladder clover (*Trifolium spumosum*), gland clover (*T. glanduliferum*) and French serradella (*Ornithopus sativus* cvv. Margurita and Erica). However, their use in farming systems was limited by lack of information on how to manage them and perceived high cost of establishment. The ability to harvest seed on farm using conventional headers and the unique hard seed characteristics of the new legumes resulted in development of the low-cost, one-time establishment options of twin and summer sowing. Robust rhizobia delivery technology was developed concurrently. Following establishment of the seedbank, new legumes can be used as an on-demand break option in the crop-pasture rotation as they, unlike traditional pasture legumes, do not need to be resown following each cropping phase. Additionally, legume species/varieties have significant potential for sustaining high levels of livestock production. Biserrula also has considerable potential in offering alternative control methods for the problematic cropping weed, annual ryegrass (Lolium rigidum).

Key words
Crop-pasture rotation, hardseeded legumes

Introduction

Southern Australian crop-pasture rotation systems have traditionally relied upon the annual legumes subterranean clover, annual medics, and where soil conditions allow, the perennial legume lucerne (*Medicago sativa*). Such pasture species have and are being used in ley and phase farming systems and require resowing at costs in excess of $200/ha. Unreliable climatic conditions, particularly false breaks and dry spring conditions, have resulted in decline in seedbank populations of annual legumes in regenerating pastures and often failure of newly sown species (Hackney et al. 2008). Lack of reliability in performance of traditional pasture species has reduced break options in cropping rotations. At the same time cropping input costs, particularly nitrogen fertiliser, have increased. Further, increased herbicide resistance in common cropping weeds are challenges facing Australian cropping systems (Powles and Yu 2010).

Howieson et al. (2000) reported on the development of a range of new species/varieties of hardseeded legumes including biserrula, bladder clover, gland clover and hardseeded species of French serradella. In small plot studies, these species/varieties had exhibited increased drought tolerance and widespread adaptation to southern Australian farming systems. In contrast to subterranean clover and annual medics, new species/varieties have the capacity for seed to be harvested relatively cheaply using conventional cereal headers. However, widespread consultation with industry in NSW (n=300) by Hackney et al. (2008) revealed little uptake of new species/varieties by farmers (<5%). Lack of reliable extension material on how to incorporate and manage them in farming systems cited by 79% of farmers as restricting uptake of new species/variety. While cautious on utilising new species/varieties in rotations, only 35% of farmers considered subterranean clover and lucerne to be highly successful in meeting their overall production goals. Farmers identified main areas of importance in future research be associated with development of new crop-

pasture rotation systems (particularly for the purpose of reducing fertiliser N reliance) and use of legumes for strategic on-off uses such as fodder conservation (36% and 42% respectively). Similar results were found by the authors in consultation with Western Australian farming groups, where in a 2004 survey, 24-47% of farmers cited establishment costs as a disincentive for sowing pastures in general. With respect to consultant, the same survey reported 53% required development of extension packages prior to recommending the use of new legume species and 26% requested educational courses specifically for consultants to develop skills in use of new annual legume species in farming systems (Hogg and Davis 2009).

As a result of this industry consultation, the authors commenced research, development and extension activities (RD&E) to deliver new low cost establishment systems for the introduction of new legumes into crop-pasture rotation systems. A key component of this program was the involvement of farmers in the initiation and development of new system technology. The remainder of this paper will discuss briefly the processes in development of new rotation crop-pasture rotation systems where pastures regenerate without the need for resowing following the cropping phase. Their potential implications for crop production, livestock production and weed management are also discussed.

Materials and Methods

Initial industry consultation in NSW and WA (Hackney et al. 2008, Hogg and Davis 2009) identified 'champion' farmers who were keenly interested in working collaboratively with the research team. This involved 3-4 farmers per region. In NSW, target research regions were the central-west and south-west slopes-Riverina and in WA the central wheatbelt and south coast. At each farm site, replicated small plot studies were established. Participating farmers were supplied with seed of one or more species to sow in 5-10 ha larger scale areas. Farmers and associated farmer groups were encouraged to undertake 'experiments' within these sown areas to test the suitability of new species/varieties in a commercial industry setting.

One of the first studies implemented in WA and NSW evaluated "twin sowing". This practice involves a late-autumn sowing with the last year of the crop rotation of unscarified or in-pod hard seed of the legumes together with the use of a rhizobial inoculant capable of colonising the soil in the absence of the host. The legume hard seed breaks down (the seed coat becomes permeable) over 12 months and emerges with the first rains in the following autumn. The legume doesn't germinate under the crop therefore a reduction in the sowing rate of the final crop is not required. This system removes competition between the crop and the pasture, which is in contrast to cover cropping that requires significant reduction in the sowing rate of the crop, sometimes by more than 50% and associated opportunity cost of reduced yield. In NSW, twin sowing and conventional sowing were compared to cover cropping – the most common method of pasture establishment used by 80% of farmers in NSW (Hackney et al. 2012). The second stage of experiments involved investigation of the use of "summer sowing" compared to conventional autumn sowing of scarified seed. As for twin sowing, summer sowing utilises unscarified (or in-pod) seed sown in February and relies on the ensuing high summer temperatures to break down this hard seed allowing for emergence on the opening autumn rain. Summer sowing requires a long-life rhizobial inoculant with the capacity to withstand soil temperatures of above 50°C at the time of sowing.

In both of the first and second stage experiments and at many of the producer-sown sites, the yield and quality of crops following the legumes were assessed and compared to the 'control' (traditional) system. Hard seed breakdown was also studied as it is critical in determining how many crops can be sown over the legumes once a seedbank had been established, without the need for re-sowing. Results in initial experiments to evaluate new species/varieties and anecdotal reports had shown considerable differences in regeneration capacity in second year stands in NSW compared to WA (Hackney et al. 2012).

The scientist-farmer teams moved on from the early focus on establishment via twin and summer sowing and associated legume agronomy and rhizobiology to assessing the livestock production potential from new legume species. In the case of biserrula, associated investigations were undertaken into the causative agents involved in a primary photosensitisation which can be experienced with this species. Additionally, the capacity to utilise biserrula's lower palatability in grazing systems through winter and spring to selectively remove the problematic but highly palatable cropping weed, annual ryegrass has been investigated.

Throughout the >10 year duration of the development of pasture-livestock-crop rotation systems with these new annual legumes, there has been considerable interaction with industry stimulated by field days, field walks, seminars, written and visual media releases.

Results and Discussion

The development and optimisation of practices for establishing and then managing pasture-crop systems based on these new hardseeded annual legumes are ongoing. The key findings so far have included:

i New "on-demand", self-sustaining crop-pasture rotation systems have been successfully developed from a one-time sowing event with adoption by industry through the target research zones.

ii Significant differences in regeneration between WA and NSW across years, particularly for biserrula. In WA, little regeneration occurs in the year following legume establishment. Therefore paddocks are usually cropped in the second year allowing hard seed break down for regeneration in year 3. In NSW, biserrula regenerates strongly in the year following sowing, allowing for paddocks to be either grazed or cropped in the second year. Results indicate that biserrula is a successful candidate for summer sowing in NSW, but not in WA due to lower hard seed breakdown in WA.

iii In WA and NSW twin sowing has been successful in establishing new legume pastures of French serradella and bladder clover in replicated experiments and on-farm broad scale sowings (Loi et al. 2008, Hackney et al. 2012, Butcher and Butcher 2015). In NSW, twin sowing has been successful in establishing biserrula but this technique has not been used for biserrula in WA (Hackney et al. 2012). Additionally, in NSW conventional cover cropping using scarified seed resulted in significant reduction (15-90%) in seed yield and seed size (up to 50%) of the sown legume and decreased production compared to twin sown treatments in the year following sowing (Hackney et al. 2012).

iv Summer sowing has been shown to be a highly effective method of legume pasture establishment across the wheatbelt of WA for French serradella and bladder clover (Loi et al. 2012). In NSW, similar success has been achieved with these species and also with biserrula where forage yield in the establishment year has been 2-16 times greater for summer sowing compared to conventional sowing (Hackney and Quinn 2015). Gland clover has also been successfully established using summer sowing (Hackney and Quinn 2015). However, some caution is required with its use for this purpose as it has a shallower root system and therefore if regional summer conditions are likely to induce rapid seed softening and early germination, greater seedling mortality may be experienced.

v A benefit of both twin and summer sowing is provision of opportunity for more rapid legume growth in early autumn, prior to onset of low temperature and frost. Both systems allow use of cheaply produced unscarified or in-pod seed, produced and harvested on-farm, enabling high sowing rates. Additionally, for species such as French serradella, utilising pod negates the requirement for the expensive process of dehulling to remove seed from the pod required for conventional sowing. Summer sowing also allows sowing of a pasture at a time of year when farmers are generally less busy. Both sowing techniques can be undertaken using conventional sowing machiney.

vi Nodulation studies have focussed upon biserrula as it has a specific inoculant that is not yet widespread in southern Australian soils. Thus, if the inoculants sown in summer or twin-sowing operations did not survive, then nodulation failure would have been evident. There has been no nodulation failure in biserrula when inoculants have been delivered either in February (summer sown) or in June, with hard seed that does not establish until the following autumn. Studies are on-going with bladder clover and serradella.

vii Crop yield and quality without N-fertiliser addition, recorded in replicated plots, has been equivalent to, or better than that achieved under a continual cropping system where N-fertiliser is provided (Hackney et al. 2012, Butcher and Butcher 2015). This has also been reported in commercial farming operations with an estimated reduction in crop production cost of $100/ha, which is attributed to reduced N-fertiliser use (Butcher and Butcher 2015).

viii Hard seed break down varies considerably between WA and NSW with rates faster in NSW (Hackney, pers. comm). There does not appear to be a linear relationship between measured breakdown rates and number of crops that can be grown over an established seedbank without affecting regeneration. For example, in WA bladder clover is usually used in one year crop-one year pasture rotation. In NSW, bladder clover has regenerated strongly following a one-year-in-four year regeneration. Biserrula has been observed to survive seven successive cropping years in northern WA wheatbelt but has not been tested beyond four years in NSW.

ix High livestock production from new legumes has been recorded in replicated plot and on-farm situations. Hackney and Quinn (2015) reported average weight gain of 350 g/head/day for suckling crossbred lambs grazing biserrula over an eight week period in an on-farm study. Similarly, in a small plot experiment, lactating merino ewes grazing biserrula over a six week period gained over 200 g/head/day, and their lambs over 250 g/head/day compared to their counterparts grazing typical volunteer pasture where ewes lost 75 g/

head/day and lambs grew at only half the rate of those on biserrula. Also in this experiment, sheep grazing Casbah biserrula pasture effectively removed ryegrass selectively over the grazing period and this has also been anecdotally reported in broadacre situations on-farm thus reducing reliance on herbicides in the following crop rotation

x Livestock production on dry legume residues over summer has also been monitored. In an on-farm study in NSW, replacement ewes weighing an average of 47 kg liveweight in December, were grazed on biserrula or bladder/gland clover residues over summer without supplementary feeding. Ewe liveweight at the end of summer was 45 kg (Mike O'Hare, pers. comm.). Initial small plot studies (Quinn, unpub.) comparing changes in liveweight of replacement ewes grazing biserrula (n=102) or wheat stubble (n=95) over a three week period in summer, reported reduced weight loss in animals grazing biserrula (-164 g/head/day) compared to wheat stubble (-248 g/head/day). Thus, requirement for supplementary feeding for livestock grazing hardseeded legume stubbles is lower than cereal stubbles and feeding costs for liveweight maintenance may be considerably reduced.

xi Primary photosensitisation can occur on biserrula dominant pastures but its incidence is greatly reduced by presence of other species, even at very low levels in the pasture sward. Photosensitisation is not observed once plants begin to senesce. If 'managed', photosensitisation appears to have no long-term impact on livestock performance (Hackney and Quinn 2015)

xii In both WA and NSW, the involvement of producers and particularly the 'champion' producers has resulted in enhanced uptake of hardseeded annual legumes into farming systems. The producer 'champions' who have been involved in the development of pasture-crop rotation systems have been instrumental in ensuring adoption as producers want 'proof' that new technology is robust outside of the confines of well-manicured replicated plots. Survey of 300 farmers in central and southern NSW five years after commencement of extension efforts showed adoption had increased from 2 to 15% over a five year period (Hackney, unpublished).

In the last ten years, a substantial breakthrough has been achieved in the uptake of new, robust, crop-pasture rotation options utilising hardseeded pasture legumes sown at unconventional times. Instrumental to the success of the RD&E presented here has been the combined efforts of a multidisciplinary team working in western and eastern regions of southern Australia. RD&E efforts have delivered sound component outcomes in the areas of agronomy, rhizobiology and livestock endeavours. More importantly however, the team has always had in mind the delivery of an overall systems outcome and the involvement of farmer champions from the outset has been instrumental in ensuring this is achieved. Commitment to systems R,D&E rather than isolated component research is required by research organisation and funding bodies to ensure robust farming systems with adequate diversity to cope with current and future biological, climatic and economic constraints can continue to be developed. Only then can we ensure the long-term viability of the Australian agricultural sector and the world population its food and fibre production support.

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Legume effects on available soil nitrogen and comparisons of estimates of the apparent mineralisation of legume nitrogen

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Abstract
Results from experimentation undertaken in southern NSW indicated that total soil mineral (inorganic) nitrogen (N) measured just prior to sowing wheat in 2012 (0-1.6m) was 42 or 92 kg N/ha greater following lupin grown for either grain or brown manure (BM) respectively, than following wheat or canola in 2011. The apparent net mineralisation of lupin organic N over the 2011/12 summer fallow was equivalent to 0.11-0.18 kg N/ha per mm rainfall and 7-11 kg mineral N per tonne lupin shoot residue dry matter (DM). This represented 22-32% of the total estimated lupin residue N at the end of the 2011 growing season. By the autumn of 2013, there was still 24-40 kg more N/ha after the 2011 lupin treatments than non-legumes. This represented an apparent mineralisation of a further 4-5 kg N per tonne of 2011 lupin's residue biomass and 14% of its N two years after the lupin had been grown. Data collated from four other experiments undertaken in different years and locations in NSW, Vic and SA generated similar increases in soil N availability in the year following legumes, and comparable estimates of N mineralisation. It was concluded that relationships averaged across all eight pulse crops grown for grain in the five separate studies (0.18 kg N/ha per mm; 10 kg N/ha per t shoot residue DM; 26% residue total N) could represent useful 'rules-of-thumb' to predict the likely affects of legumes on the N dynamics of dryland cropping systems.

Key words
Pulses; canola; cereals; on-farm; grower group

Introduction
Even though elevated concentrations of soil mineral nitrogen (N) (i.e. nitrate+ammonium) are frequently observed after legume crops and pastures (Angus *et al* 2015), only a fraction of the N in legume residues remaining at the end of a growing season becomes available immediately for the benefit of subsequent cereal crops (Peoples *et al* 2009). The microbial-mediated decomposition and mineralisation of the N in legume organic residues into plant-available inorganic forms is influenced by three main factors: (i) rainfall to stimulate microbial activity, (ii) the amount of legume residues present, and (iii) the N content (and "quality") of the residues. Field data are utilised to estimate the apparent mineralisation of N from legume stubble, or brown manure (BM; where a legume is killed with "knock-down" herbicide prior to maturity to provide a boost in available soil N and/or to control difficult to manage weeds). The rate of mineralisation is expressed per mm of summer fallow rainfall, per tonne (t) of above-ground legume residue dry matter (DM), and kg total residue N (i.e. above-ground N + N estimated to be associated with the nodulated roots).

Methods
The experiment was located at an on-farm field site at Junee Reefs, NSW, Australia and undertaken in partnership with the FarmLink Research grower group. Soil pH ($CaCl_2$) was 5.50 in the surface 0-10 cm. Soil mineral N prior to the commencment of the experiment in April 2011 (0-1.6m) was 100 kg N/ha. The following crop treatments were replicated four times and were sown in a randomized design in 2.5 x 20m plots in either late-April (lupin and canola) or mid-May (wheat):
(1).Lupin: cv Mandelup - for grain; inoculated at sowing + 75 kg kg/ha MAP (8 kg N/ha);
(2).Lupin: cv Mandelup - for brown manure (BM); inoculated at sowing + 25 kg/ha MAP (3 kg N/ha), with the crop being terminated in September using knock-down herbicides (450 g/L glyphosate (Roundup CT) @ 2 L/ha + 300 g/L clopyralid (Lontrel) @ 150 ml/ha + 240 g/L carfentrazone-ethyl (Hammer) @ 25 ml/ha);
(3).Canola: cv Crusher TT– for grain; (Jockey + Gaucho) + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) and 80 kg/ha ammonium sulphate (17 kg N/ha) in-crop;
(4).Wheat: cv Lincoln – for grain; Raxil + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) in-crop.

Above-ground biomass was determined immediately prior to lupin BM termination, or 4 weeks later in the case of the grain crops at around the time of lupin mid-pod fill by removing all plants from 4 × 1m sections of row from each plot. Shoot DM was measured after drying subsamples at 70ºC. Grain yield was determined

at maturity by the mechanical harvesting of the central 16m of each plot. Dried plant and grain samples were analysed for % N and ^{15}N abundance using a 20-20 stable isotope mass spectrometer (Europa Scientific, Crewe, UK). At the end of April 2012, each of the replicated plots was sampled for soil mineral N analysis to a depth of 1.6m, and all treatments were sown to Spitfire wheat in mid-May. Further soil samples were again collected for soil mineral N analysis in April 2103. Four additional studies similar to that outlined above at Junee Reefs, have been undertaken in collaboration with the Riverine Plains grower group, Birchip Cropping Group (BCG), Mackillop Farm Management Group (MFMG), NSW DPI, Vic DEPI and SARDI in NSW, Victoria and South Australia. These experiments are not described in detail here; however, summaries of estimates of apparent mineralisation of legume from these studies are included in the current paper for comparative purposes.

Calculations

Estimates of total plant N were derived from the peak biomass shoot N data by assuming ~25% total plant N for lupin, and ~30% for wheat and canola N was associated with roots (Unkovich et al. 2010). The last 1m at each end of the canola and wheat plots received no fertiliser N and plants were collected from these areas at the same time as the lupin sampling and were used as "reference" plants to allow the determination of the proportion of the lupin N derived from atmospheric N_2 (%Ndfa) using the ^{15}N natural abundance technique, and these values were combined with lupin total N data to calculate inputs of fixed N:

Amount of N_2 fixed over the growing season (kg N/ha)

= (total lupin N) x (%Ndfa/100) Equation [1]

The total amounts of N remaining in crop vegetative residues and roots at the end of the 2011 growing season were calculated as:

Total residue N

= (total crop N) – (grain N removed) Equation [2]

The net effect of lupin treatments on available soil N was calculated from the differences in soil mineral N data (0-1.6m) following lupin and wheat in April 2012 and April 2013. The apparent net mineralisation of lupin N was calculated in several different ways from mean treatment data by assuming negligible net N release from the 2011 wheat residues :

Apparent mineralisation of legume residues (kg N/ha per mm fallow rainfall)

= [(mineral N after legume) – (mineral N after wheat)] /(fallow rain) Equation [3]

Apparent mineralisation of legume residues (kg N/ha per tonne shoot residue DM)

= [(mineral N after legume) – (mineral N after wheat)] /(legume shoot residue DM) Equation [4]

Where shoot residue = (peak biomass DM) – (grain yield)

Apparent net mineralisation of legume N (% 2011 total residue N)

= 100x [(mineral N after legume) – (mineral N after wheat)] /(total legume residue N) Equation [5]

Analysis of variance was undertaken on the DM, N and soil mineral N data to provide least significant difference (LSD) determinations. In each case P values were <0.001. However, no such statistical analyses were possible for the derived estimates of apparent mineralisation obtained using Equations [3]-[5], but as DM, N and soil mineral N provide the basis of the estimates, significant differences in these main factors should be sufficient to confer differences in apparent mineralisation.

Results

Crop growth in 2011

The 2011 growing season rainfall (GSR: April-October) was 216 mm which was lower than the 311 mm long-term average, but heavy rainfall in February 2011 (226 mm) resulted in an annual total of 639 mm, around 130 mm wetter than the long-term average (506 mm). The soil moisture profile at the beginning of the growing season was close to full which contributed to good crop establishment and growth, and respectable grain yields (Table 1). The lupin treatments were calculated to have accumulated a total of 290 kg N/ha (lupin BM) and 398 kg N/ha (lupin grain crop) of which 241 kg N/ha (83±3%) and 338 kg N/ha (85±4%) were estimated to have been derived from N2 fixation, respectively (LSD=35; P<0.001). The crop harvest indices (grain as % of above-ground DM) were 35% for lupin, 43% for wheat and 30% for canola. The N content of the stubble remaining after grain harvest was higher for the lupin crop (1.4%N; C:N ratio=28) than either canola (0.7%N; C:N=60) or wheat (0.3%N; C:N=130), but the shoot material in the lupin BM treatment had the highest "quality" (2.6%N; C:N=15). The total amounts of N calculated to be remaining in the vegetative residues and roots of the lupin treatments at the end of the 2011 growing season were between 3- to 5-fold higher than where wheat had been grown (Table 1).

Table 1. Above-ground dry matter (DM), N accumulation, grain yield and the amount of N estimated to be remaining in vegetative and root residues at the end of the growing season where wheat, canola, or lupin was grown for either grain or brown manure (BM) at Junee, NSW in 2011[a]

Crop grown in 2011	Peak biomass (t DM/ha)	Above-ground N (kg N/ha)	Total crop N[b] (kg N/ha)	Grain yield (t/ha)	Grain N harvested (kg N/ha)	N remaining in residues (kg N/ha)
Lupins BM	8.4	218	290	0	0	290
Lupins	9.9	300	398	3.5	210	188
Wheat +N[a]	11.1	106	151	4.8 (10.4% protein)	87	64
Canola +N[a]	10.6	164	207	3.2 (46% oil)	94	113
LSD (P<0.05)	1.3	36	46		11	22

[a] N fertiliser was applied to wheat @ 49 kg N/ha and canola @ 66 kg N/ha.
[b] Above-ground data adjusted to include an estimate of below-ground N (Unkovich et al. 2010).

Trends in available soil mineral N, and estimates of N mineralisation in 2012 and 2013

Soil mineral N measured in April 2012 were similar following the 2011 wheat and canola crops (76-77 kg N/ha), but were 42 or 92 kg N/ha greater than after wheat where lupin had been grown for grain or BM, respectively (Table 2). Apparent net mineralisation over the wet 2011/12 summer fallow (515 mm Sept 2011-April 2012 after BM, or 386 mm Nov 2011-April 2012 for grain crops cf 214 mm long-term average) represented the equivalent of 0.11-0.18 kg N/ha per mm rainfall, 7-11 kg N per tonne residue DM, and 22-32% of the 2011 lupin residue N. Soil mineral N was still 24 or 40 kg N/ha higher in soil in the lupin-wheat sequences than continuous wheat in April 2013 (Table 2), which was equivalent to a further 4-5 kg N per tonne of the 2011 residue DM, with 14% of the residue N subsequently becoming available.

Table 2. Concentrations of soil mineral N (0-1.6m) measured in autumn 2012 and 2013 following either wheat, canola and lupin grown for grain or brown manure (BM) at Junee, NSW in 2011, and calculations of the apparent net mineralisation of lupin N from 2011 expressed per tonne shoot residue dry matter (DM), or as a % of total residue (above+below-ground) N.

Crop grown in 2011	Soil mineral N autumn 2012	Apparent mineralisation of legume N		Soil mineral N autumn 2013	Apparent net mineralisation of legume N	
	(kg N/ha)	(kgN/t DM)	(% residue N)	(kg N/ha)	(kgN/t DM)	(% residue N)
Lupins BM	169	11	32%	167	5	14%
Lupins	119	7	22%	151	4	14%
Wheat	77	-	-	127	-	-
Canola	76	-	-	115	-	-
LSD (P<0.05)	35			20		

Comparisons of legume effects on soil mineral N and N mineralisation at other locations

Each of the four independent experiments undertaken in different locations, years, and soil types indicated improvements in soil mineral N after legumes, and comparable estimates of apparent net mineralisation of legume N (Table 3) were calculated to those obtained for Junee Reefs (Table 2).

Table 3. Examples of the impact of prior legume crops on additional autumn soil mineral N compared to following wheat, and estimates of the apparent net mineralisation of legume N at different locations in NSW, VIC and SA.

Location and year	Legumes grown for grain or BM in previous year	Additional soil mineral N	Apparent net mineralisation of legume N		
		(kg N/ha)	(kg N/ha per mm)	(kgN per t DM)	(% residue N)
Breeza, NSW 1998	Chickpea	38	0.14	12	30
	Faba bean	47	0.17	18	36
Hopetoun, Vic 2010	Field pea	47	0.17	6	17
	Vetch BM	88	0.24	10	24
Culcairn, NSW 2011	Lupin	61	0.10	11	30
	Faba bean	88	0.15	11	27
Naracoorte, SA 2012	Field pea	28	0.23	6	18
	Faba bean	42	0.34	10	31
Mean		55	0.19	11	27

Discussion

In common with many previous field experiments where the accumulation of soil mineral N after legumes has been compared with wheat (Angus *et al* 2015), increased concentrations of available soil N were detected following all legume species grown at five different locations across south-eastern Australia (Tables 2 and 3). The estimates of apparent mineralisation of legume N calculated from these data represent the net effect of growing legumes for BM or grain on available soil N regardless of whether the mineral N was derived directly from above- and below-ground legume residues, arose from "spared" nitrate due to a lower efficiency of legume roots in the recovery of soil mineral N, and/or an additional release of N from the soil organic pool (Peoples *et al*. 2009). Although soil mineral N was not determined following grain harvest at the end of the 2011 growing season at Junee Reefs, given that lupin assimilated only 49-60 kg N/ha from the soil (calculated as: total lupin N - N fixed) while 151 kg N/ha was accumulated from the soil and fertiliser by wheat, it is likely that some of the additional available soil N measured after lupin represented unutilised nitrate carried over from the previous season.

The measured improvements in soil mineral N, and the derived estimates of apparent mineralisation of legume N, were similar across all five studies (Tables 2 and 3). As might be expected from the lower C:N ratio of the BM residues and the longer period available for mineralisation to occur (Peoples et al 2009), the calculated estimates of mineralisation were greater, for BM treatments than where pulses were grown for grain (Junee Reefs and Hopetoun). Apparent mineralisation also tended to be higher after lupin or faba bean than following chickpea or field pea (Breeza and Naracoorte average of 14 kg N/ha per t shoot residue DM and 33% residue total N cf 9 kg N/ha per t shoot residue DM and 22% residue total N; Tables 2 and 3).

Conclusions

The relationships between summer fallow rainfall, legume residue DM, or total N, and soil mineral N measured the following autumn, were generally similar across five different experiments and were comparable to estimates previously determined for pasture legumes (Angus and Peoples 2012). This suggests that average estimates of apparent mineralisation might represent useful 'rules-of-thumb' to predict the likely additional mineral N provided by legumes in dryland grain production systems of south-eastern Australia. More experimental data are required to ensure the reliability of such determinations. This is especially important to confirm whether there are consistent differences between legume species and, in the case for legume BM treatments, to quantify the impact of timing of crop termination on the accumulation of mineral N. Of the three different measures of apparent mineralisation examined here, perhaps the estimate of around 10 kg additional soil mineral N/ha per tonne shoot residue DM might be the simplest for farmers and their advisors to apply. Since around one-third of the above-ground biomass is commonly harvested in grain in most pulse crops (i.e. Harvest Index = ~0.33), it should be relatively easy for farmers to calculate residue DM directly from grain yields (i.e. ~ twice the tonne grain harvested/ha). Consequently, 20 x tonne grain yield/ha could be a useful guide to the expected additional mineral N prior to sowing a following crop and provide a basis for modifying decisions on N fertiliser applications. However, it should be recognised that the end result will ultimately be mediated by rainfall over the summer fallow. There are potential negative implications of under-estimating available N using the proposed relationship as supplying too much fertiliser N to wheat in a dry cropping year could increase the risk of yield reductions due to haying-off.

Acknowledgements

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Additional nitrogen mineralisation and crop uptake following tropical forage legumes is lower if shoot biomass is removed

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Abstract
Tropical pasture legumes used for hay or cut and carry fodder increase dietary protein for ruminants and can also provide nitrogen (N) for subsequent crops. An experiment was conducted at Gatton, Queensland, to quantify N mineralisation and crop uptake following the tropical herbaceous legumes Butterfly pea (*Clitoria ternatea* cv. Milgarra) and Centro (*Centrosema pascuorum* cv. Cavalcade) when shoot biomass was removed or retained during the growing period (8 months). Soil mineralisation (0-0.45 m) was compared to plots following a maize control using in-situ tubes and an oven incubation study. For the incubation study, after 17 weeks soil nitrate following legumes with biomass retained was 115 kg NO_3-/ha higher than following maize. In the in-situ cores, retention of legume biomass increased mineralisation during the oat crop (3 months) from 41-56kg N/ha to 78-125kg N/ha. Consequently, legumes with biomass removed provided an additional 2-23kg N/ha to the oats, compared to maize, but, less than the additional 53-90kg N/ha when biomass was retained. Retention of legume biomass doubled N uptake by the oat crop from 37 kg N/ha to 82 kg N/ha and increased oat biomass by 50%. Despite this, soil N post-oats and mineralisation rates indicate that mineralisation of root material for legumes with biomass removed may still become evident in a subsequent maize crop. These results indicate that removing shoot biomass of Butterfly pea and Centro for cut and carry or hay conservation considerably reduces the N benefit to the subsequent crop.

Key words
Pasture legume, ley legume, defoliation, farming systems, sub-tropical, N-fertiliser substitution value

Introduction
In tropical and sub-tropical mixed farming systems tropical pasture legumes can be used to increase soil nitrogen (N) for subsequent cereal crops as well provide high quality fodder to increase livestock growth rates. In northern Australia, legume-leys can increase the productivity of subsequent cereal crops, however where shoot biomass is removed – such as occurs in haymaking or cut and carry systems – the N benefit to the subsequent cereal crop is reduced. Research comparing tropical pasture legumes with cereal rotations shows that, even with defoliation, a legume rotation can increase grain yield and N uptake of the subsequent cereal crop, however the N benefit is highly variable with changes in the yield of the subsequent cereal crop ranging from -30% to +20% (Smyth et al. 1991; Oikeh *et al*. 1998). While tropical legumes Centro (*Centrosema pascuorum*) and Butterfly pea (*Clitoria ternatea*) also suit haymaking and cut and carry systems, there is limited research into their N contribution to subsequent cereal crops when shoot biomass is removed. This paper describes an experiment to quantify N mineralisation and crop uptake following Butterfly pea and Centro where shoot biomass was removed or retained.

Methods
Field and in-situ micro-plot experiment
An experiment was conducted on a black vertosol at Gatton, Queensland. Four replicate plots (6 m by 12 m) of Butterfly pea (*Clitoria ternatea* cv. Milgarra), Centro (*Centrosema pascuorum* cv. Cavalcade) and maize were planted in a randomised split-plot design, with two legume sub-plots (6 m by 6 m) where shoot biomass was either retained or removed 50 mm above ground level. Inoculated legume and maize seed was planted following recommended district practice on 12 September 2013, after which the experiment was irrigated every 2 weeks. Shoot biomass was removed twice for Centro – 144 days after sowing and at termination – and three times for Butterfly pea – 89 and 144 days after sowing and at termination. Maize grain and biomass above 15 cm was harvested at maturity on 3 February 2014 and then fallowed until legumes were terminated with herbicide 64 days later on 8 April 2014. After spraying, sub-plots with shoot biomass retained were mulched. Following the legume rotation, an oat cover crop was sown over the whole experiment on 28 May

2014. To measure in-crop mineralisation, one PVC tube (100 mm diameter by 0.6 m long) was installed in each plot to exclude oat roots. The tubes – or 'micro-plots' – were driven 0.5 m into the ground and then trimmed to leave 20 mm above ground. The oat cover crop was terminated with herbicide on 14 August 2014.

Soil nitrate (NO_3-) concentrations and soil water content were measured prior to starting the experiment and then in each replicate treatment plot following both the legume and oat rotations. For each sub-plot, soil samples were collected to a depth of 0.45 m for nitrate and 1.5 m for water content and, at oat sampling, soil was collected to 0.45 m in each micro-plot. Samples were separated into 0-0.15, 0.15-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.90, 0.90-1.20 and 1.20-1.50 m layers, with subsamples removed for soil nitrate and gravimetric water content analysis. Soil nitrate was analysed at a commercial laboratory using a 1:5 soil:water extraction and volumetric soil water content was calculated using gravimetric water content and estimated bulk density.

Plant biomass cuts were taken from each replicate sub-plot at legume biomass removal, legume termination and oat termination. Biomass was measured by collecting shoot material above ~10 mm in two quadrats (0.5 m^2 each). Shoot samples were divided into leaf and stem, dried at 80°C for 3 days and a ground subsample was analysed for total N (mg N g^{-1}) using a calibrated NIRS. Total and retained biomass N was calculated as:

Total shoot biomass N = [(total shoot DM) x (shoot %N/100)] [1]

Retained shoot biomass N = [(retained shoot DM) x (stem %N/100)] [2]

As root nitrogen is not accounted for in biomass N calculations, total plant N was calculated by multiplying biomass N by a root factor estimating the proportion of below-ground plant N.

Total plant N = [(total shoot biomass N) x (root factor)] [3]

A root factor of 1.49 was used for Centro (33% below ground N), 1.8 for Butterfly pea (45% below ground N), 1.85 for oats (46% below ground N) and 1.58 for maize based on mean below ground N (37%) of a range of temperate cereals (Wichern *et al*. 2008; Unkovich et al. 2010; Peoples *et al*. 2012).

Oven incubation experiment

At legume termination seven soil cores (32 mm) were collected in each replicate sub-plot to 0.6 m deep. Each core was placed in a PVC tube (33 mm diameter x 0.6 m long) and sealed with a PVC cap on the base and 4 layers of Gladwrap™ at the top. Soils were placed in an oven at 33°C and were re-wet to original weight every two weeks. Tubes were destructively sampled at 6 times over the incubation period, 0, 14, 47, 76, 119 and 191 days and gravimetric water content and nitrate were measured for one tube from each sub-plot. Samples were processed as described above, except soil nitrate was analysed using a 2M KCl extraction. Analysis of variance in Genstat 16.1 (VSV International Ltd. Hemel Hempstead, UK) was used to determine statistical differences in soil N for field and incubation studies as well as biomass production and nitrogen uptake.

Results

All legume treatments produced >12t DM/ha, however estimated total N inputs were 266-322 kg N/ha higher ($p<0.05$) when shoot biomass was retained (Table 1). Maize grain yield averaged 4.36 t/ha and 12.2 t/ha of stover was produced.

Table 1. Total accumulated N retained on plots following legumes with shoot biomass removed or retained

Legume	Shoot biomass	Total retained shoot N (kg N/ha)	Total retained plant N (kg N/ha)*
Butterfly pea	Retained	339	610
	Removed	17	288
Centro	Retained	293	437
	Removed	27	171
Maize	Removed	4	49

*Adjusted to include below-ground contributions of nitrogen using root-factors

Incubation nitrogen mineralisation study

In the incubation study, N mineralisation rates following legumes with shoot biomass retained averaged 1 kg NO_3-/ha/d, compared with 0.43 kg NO_3-/ha/d where shoot biomass was removed and 0.25 kg NO_3-/ha/d following maize (Figure 1). Consequently, after 17 weeks incubation, soil nitrate following legumes with shoot biomass retained was 115 kg NO_3-/ha higher ($p<0.05$) than following maize. However, where shoot biomass was removed there was no significant difference between legumes and maize.

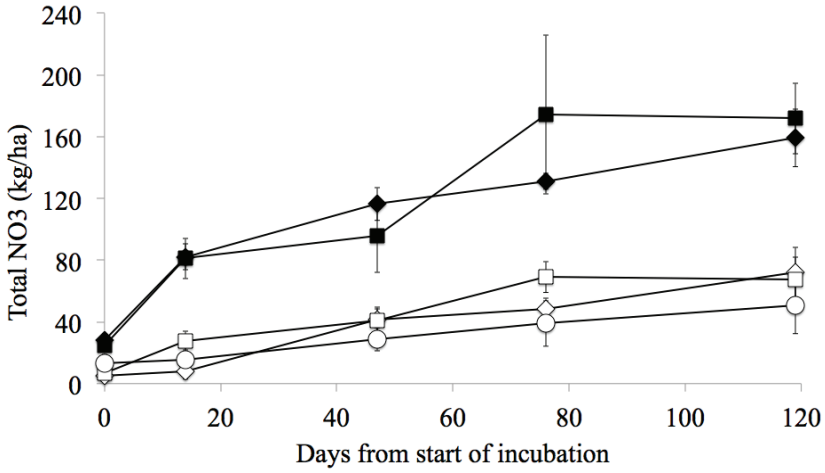

Figure 1. Soil nitrate (0-0.45 m) during incubation of soil cores at 33°C following a legume – Butterfly pea with biomass retained (black square), Centro with biomass retained (black diamond), Butterfly pea with biomass removed (white square), Centro with biomass removed (white diamond) – or maize (white circle) rotation

Micro-plot nitrogen mineralisation study

Soil N was 42 kg N/ha before legume planting and 16 kg NO_3-/ha at legume termination; there was no difference ($p=0.553$) in soil N amongst all treatments immediately after the legume crop. Despite this, in-crop mineralisation during the oat crop was higher ($p<0.001$) were shoot biomass was retained, with up to an additional 88 kg NO_3-/ha mineralising when shoot biomass was retained instead of removed (Table 2). However, when biomass was removed there was no significant difference in mineralisation between the two legumes or maize. After oat termination, residual soil N was higher following Butterfly pea where shoot biomass was retained ($p<0.05$); there was no significant difference between the other four treatments.

Table 2. Soil volumetric water content at oat planting, soil mineral nitrate-N following legume and oat rotations and in-crop mineralisation (water content 0-1.5 m; nitrate 0-0.45 m)

Previous rotation	Shoot biomass	Volumetric water content at oat planting (mm)	Soil N at oat planting (kg NO_3-/ha)	Residual soil N in field at oat termination (kg NO_3-/ha)	Soil N in micro-plots at oat termination (kg NO_3-/ha)	N mineralisation after legume termination (kg NO_3-/ha)*
Butterfly pea	Retained	190	12	73	137	125
	Removed	201	9	22	49	41
Centro	Retained	184	22	33	100	78
	Removed	189	13	37	70	56
Maize	Removed	217	22	20	47	25

*Estimated for 132 day period by subtracting soil N at legume termination from soil N inside the micro-plots at oat crop termination

Oats biomass production and N uptake

Oat DM production was greatest ($p<0.001$) following maize and when legume shoot biomass was retained with a mean yield of 3.2 t DM/ha, or 70% more than when legume biomass was removed (Table 3). Although oat DM production was similar following both Centro and Butterfly pea, oat shoot N % was higher ($p<0.05$) following Centro when shoot biomass was retained. Retaining legume shoot biomass increased ($p<0.001$) oat shoot N % and increased estimated uptake of soil N by the oat crop by up to 152% ($p<0.001$).

Discussion

This study indicated that removing shoot biomass of Butterfly pea and Centro for cut and carry or hay conservation considerably reduces the N uptake of the subsequent crop, resulting in little to no N benefit when compared to a previous cereal crop. There were no differences in N mineralisation in the incubation

and micro-plot studies between soils following maize and legumes with biomass removed.

Table 3. Oat biomass and nitrogen accumulation following a legume rotation

Legume	Shoot biomass	DM production (t DM/ha)	Leaf nitrogen (%N)	Accumulated shoot N (kg N/ha)	Accumulated total plant N (kg N/ha)
Butterfly pea	Retained	3.03	1.23	38	70
	Removed	1.97	1.00	20	36
Centro	Retained	3.09	1.66	51	94
	Removed	1.86	1.09	20	37
Maize	Removed	3.60	1.20	44	81

However, as approximately 90% of total legume plant N was below ground following biomass removal, there is potential for additional mineralisation over a longer period given that root decay is commonly slower than the decay of shoots and stems (Abiven *et al*. 2005).

Retaining shoot biomass significantly increased soil N mineralisation, oat crop N uptake and biomass production. These differences were driven by the additional 266-322 kg N/ha of plant N that was retained and mulched and subsequent higher soil N mineralisation rates. Consequently, when legume shoot biomass was retained rather than removed, N uptake by the oat crop increased from 37 to 82kg N/ha and oat DM production increased from less than 2t DM/ha to over 3t DM/ha. These differences between retention and removal of shoot biomass are considerably larger than other research in Northern Australia, which found that following *Stylosanthes hamata*, N uptake by the subsequent maize crop was only 4 kg N/ha higher where shoot biomass was retained rather than removed (Jones et al. 1996).

Comparison of maize and legumes with biomass retained showed that oat DM production and N uptake were similar following both treatments. This is attributed to a longer fallow period after maize, resulting in an additional 2 months for accumulation of soil water and N mineralisation, with an extra 26 mm of soil water available at sowing following maize compared with legumes. In contrast to this, research shows that, given the same fallow period, a legume phase can provide significantly more soil N at sowing than a cereal rotation (Armstrong *et al*. 1997).

Conclusion

Using Centro or Butterfly pea in hay or cut and carry systems considerably reduces the N benefit to the subsequent crop, resulting in N inputs that are too small to substitute N fertiliser or increase crop yield. In contrast, results showed that green manuring Centro and Butterfly pea can potentially increase the productivity of the subsequent cereal crop. While these results indicate that neither of these options can provide both high quality fodder and increased soil N, careful grazing of Centro and Butterfly pea is another option which could potentially achieve these dual benefits.

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Evaluation of APSIM to simulate nitrogen fixation and uptake in diverse legume species across Australia

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Abstract
Quantification of the nitrogen (N) that legume crops contribute to subsequent crops in a rotation is critical in developing sustainable cropping systems. Process-based simulation models, such as APSIM (the Agricultural Production Systems Simulator) are potential tools to investigate interactions between season, soil chemistry, legume species, and the N cycle. However, even though there is a capacity to simulate N fixation, the performance of APSIM to predict N fixation has not been well validated. Here, the parameterised model was tested for the simulation of N uptake and N fixation in four crop legumes (lupin, chickpea, field pea, and peanut) in tropical, subtropical, semiarid and Mediterranean environments across Australia. The simulations varied in location, cultivar, sowing date, climate, soil type, irrigation and applied fertiliser N. In general, N uptake and fixation in aboveground biomass were reasonably well simulated for all legumes, with 93% of the variation in observed N accumulation and 85% in N fixation being explained by the model. There was a close relationship between simulated aboveground biomass and N fixation, indicating that an adequate simulation of aboveground biomass is a prerequisite to well simulate N fixation.

Key Words
APSIM, legume crops, N uptake, biological N fixation

Introduction
Supply and availability of Nitrogen (N) are important components in the productivity of cropping systems. Legumes can contribute substantial N to farming systems (Peoples et al., 1995), through the process of biological N fixation. However, the processes of biological nitrogen fixation are complicated. The complex interplay between seasons, soil chemistry, legume species and N cycles have been experimentally studied from plant to field crops (Masson-Boivin et al., 2009). However, long-term studies of N uptake and fixation by legumes are needed to understand the contribution of biological N fixation to sustainable agricultural systems.

Process-based simulation models, such as APSIM (Holzworth et al., 2014), are valuable tools to investigate the interactions of plant and soil processes in response to climate and management changes. Simulation models can also potentially extend the timescale of the outcomes of field experiments. The APSIM model simulates growth and development of diverse legume species, with a capacity for simulating N demand, N uptake and fixation (Robertson et al., 2002). However, it is still unclear whether the model is able to simulate N uptake, fixation and their responses to legume types, climate, and soil water and nitrogen levels, which are essential to successfully simulate the N cycle within the legume-based cropping system.

Legume crops, such as arrow-leafed lupin (*Lupinus angustifolius* L.), chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.) and peanut (*Arachis hypogaea* L.) have played an important role in Australian farming systems over the past decades, because of attractive cash returns from their yield, inputs of biologically fixed N to soil and beneficial effects on controls of diseases and weeds when they are rotated with cereals (Jensen et al., 2006). We tested the performance of APSIM v.7.6 in simulating N uptake and symbiotic N fixation for lupin, chick pea, field pea and peanut using experimental results across Australia.

Method
The APSIM legume model
The APSIM-legume model has the functionality to simulate the development, growth, crop N uptake, N fixation and N partitioning for a wide range of legume species, such as lupin, chickpea, field pea and peanut, using a generic crop model template (Robertson et al., 2002). However, it is worthwhile to note that N fixation is modelled simplistically. N fixation (N_fixation, Eqn. 1) is only affected by crop biomass

(biomass), crop N fixation capacity (N_fix_rate) and water stress (swdef (fixation)), the latter of which is a distinctive feature of arid and semiarid regions.

N_fixation = N_fix_rate * biomass * swdef (fixation) (1)

Model evaluation

Available field experimental data from published and unpublished studies were used for model evaluation of legume growth, N uptake and fixation, including lupin during 1994-1996 at Moora in Western Australia (Anderson et al., 1998a, 1998b), chickpea with three N fertiliser treatments (0, 50 and 100 kg N ha-1 were applied before sowing) during 1999 in Queensland (Turpin et al., 2002), field pea obtained from Wongan Hills site in 1988, Beverley and Mt Barker sites in 1989 in South Western Australia (Armstrong et al., 1994a, 1994b) and peanut during 1996-1997 and 1998-1999 at Goodger and during 1998-1999 at Kingaroy in Queensland (unpublished data). These data were selected because they all had measurements of aboveground biomass, yield, N uptake and N fixation (by 15N analysis).

The primary objective of this study is to evaluate the performance of APSIM in simulating nitrogen fixation and uptake in legumes, not in simulating crop phenological development. Therefore the default cultivar parameters for lupin (cv. Merrit and cv. Gungurru), peanut (cv. Streeton) were primarily adopted from APSIM v7.6. The parameters (thermal time target from to flowering to start of grain filling, thermal time target from start grain filling to end grain filling and radiation use efficiency) of chickpea were modified to improve the biomass simulations. For field pea crop, cultivar parameters (cv. Wirrega and Dinkum) were not available and we used the parameters for similar cultivars in APSIM.

Results

Generally, APSIM was able to simulate the observed N accumulated in aboveground biomass for the four legume crops lupin, chickpea, field pea, and peanut (Fig. 1a-d), although peanut biomass N was moderately overestimated in the low N treatment in the dry season (Fig. 1d). For all crops, the model explained about 93% (90-95% for individuals) of the variation in biomass N, with a RMSE of 24.5 kg N ha-1 DM (14.5-34.1 kg N ha-1 DM for individuals; Table 1; Fig. 1).

The model simulated the fixed N in aboveground biomass reasonably well for each crop (Fig. 2a-d). The discrepancies of fixed N for field pea (Fig. 2c) indicated that the model tended to underestimate N fixation under water-limited conditions (267 mm of precipitation at Avondale in 1989) and overestimate it under wet conditions (421 mm at Mt Barker in 1989). The model could explain at least 79% of the variations in observed N fixation in above-ground biomass for each crop, with lower RMSE values. Overall, APSIM could explain 85% of the variation in observed N fixed in aboveground biomass for all crops (Table 1). These results indicate that the APSIM model is able to simulate N uptake and N fixation of legumes and its response to water and N supply.

Table 1. Evaluation results for APSIM predictions of N uptake and fixed N in biomass of four crops.

Model attribute	r^2 [1]	a[2]	b[3]	RMSE (kg N ha^{-1})[4]
Biomass N	0.93	1.10	-3.5	24.5
Fixed N	0.85	0.97	-2.8	22.7

[1] Coefficient of determination (r2); 2Slope of linear regression; 3Intercept of the linear regression; 4Root mean squared error

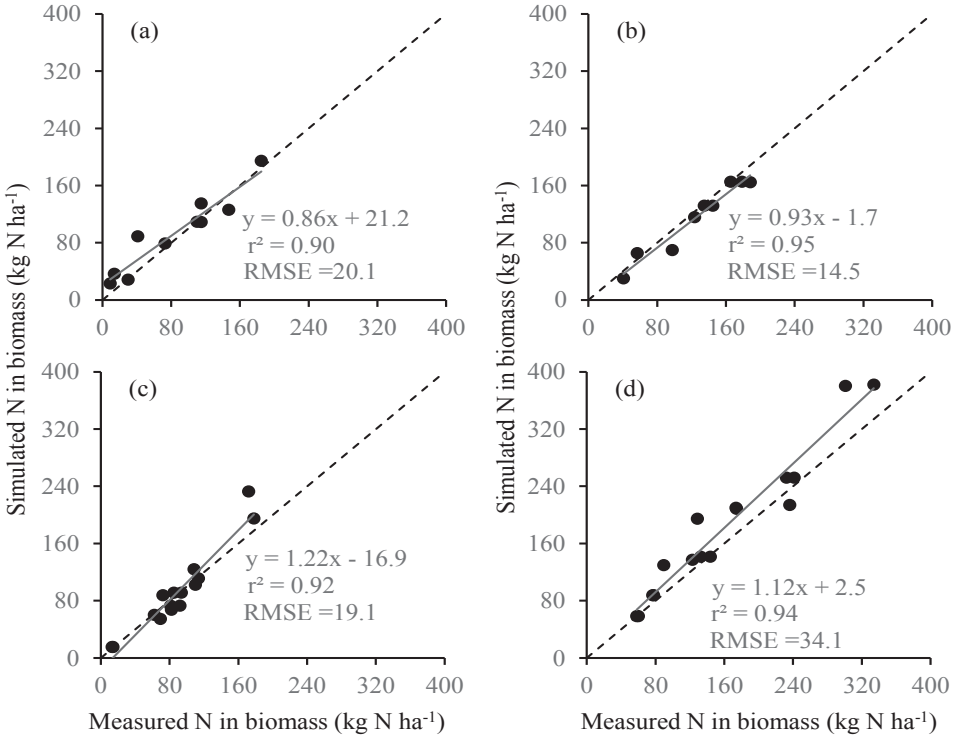


Figure 1. Comparison of observed and simulated N in aboveground biomass for lupin (a), chickpea (b), field pea (c) and peanut (d).

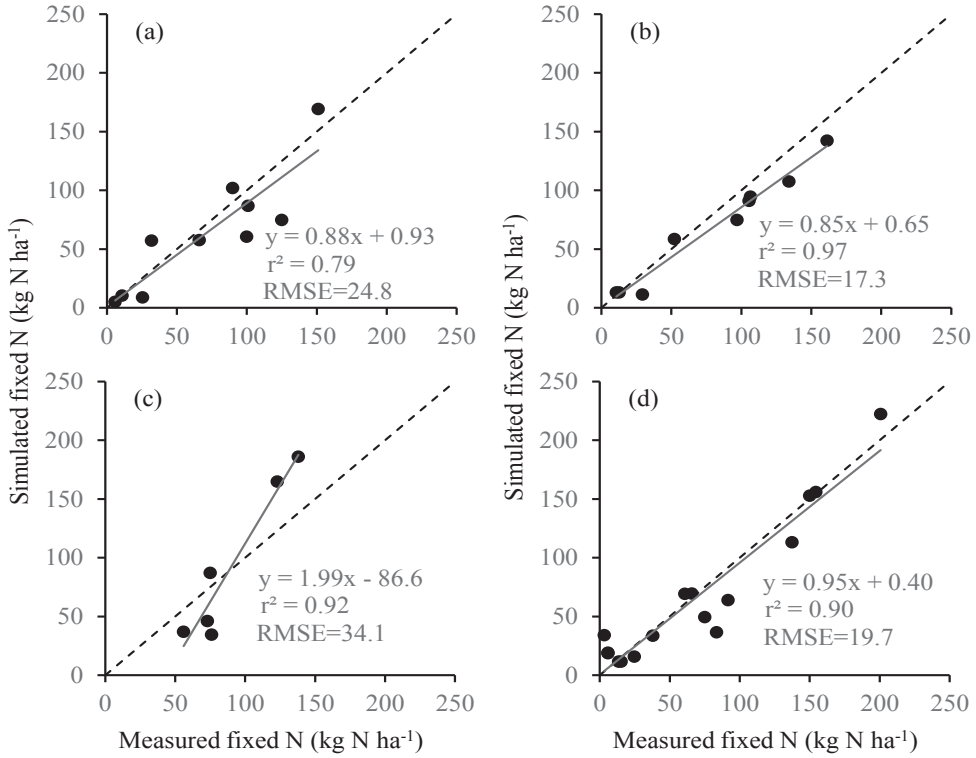
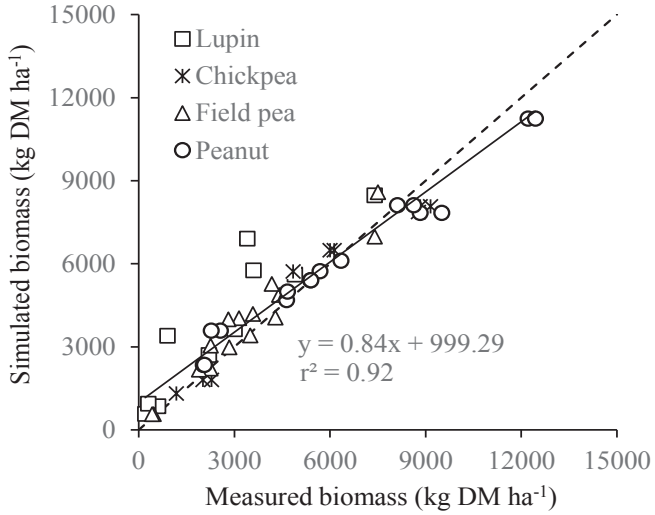


Figure 2. Comparison of observed and simulated fixed N in aboveground biomass for lupin (a), chickpea (b), field pea (c) and peanut (d). Unit of RMSE; kg N ha-1.

Figure 3. Comparison of observed and simulated values of biomass for all crops (lupin, chickpea, field pea and peanut). DM: biomass.



Conclusion

The good agreement between simulated and measured N fixation indicates that APSIM has captured the main environmental factors (leaf area development, radiation use and temperature) to estimate N fixation by legumes. We propose that simulation models such as APSIM are valuable tools to improve the knowledge about the role of legumes in farming systems. We conclude that the aboveground biomass must be simulated well to successfully simulate N accumulation and N fixation.

Acknowledgement

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Model-based evaluation of yield performance and agronomic options for lupins in the southern wheatbelt, Western Australia

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Abstract

Currently, narrow-leafed lupin (Lupinus angustifolius L.), the largest grain legume crop in Western Australian (WA), is mainly grown in the northern agricultural region. However, due to a cooler and longer growing season yield potential may be higher in the southern wheatbelt. Our capacity to assess this experimentally is limited by the lack of vernalisation insensitive long season varieties. This study used a modelling approach to test this hypothesis by comparing six selected locations in high, medium and low rainfall zones in the northern and southern WA wheatbelt. On average, simulated lupin yields in the medium and low rainfall zones in the southern region were 15% higher than in the medium and low rainfall zones in the northern region. However, lupin yield in the southern high rainfall zone was slightly lower due to less solar radiation. Lupin may potentially be integrated into farming systems in the south if longer maturity varieties become available. Overall in the medium and high rainfall zones in southern WA, higher yield would be obtained when sown in early April with late-maturity cultivars, while in the low rainfall zone, lupin crops would benefit more from early-maturity cultivars when sown later than mid-April, if opening rains occur. While, further assessment of lupin agronomy, production and the balance with other crops in terms of economic and environmental performances should be performed, this preliminary work suggests that breeders should pay attention to developing varieties with a longer maturity for the southern wheatbelt of WA.

Key words

Yield potential; Sowing date; Vernalisation sensitivity; APSIM

Introduction

Narrow-leafed lupin (*Lupinus angustifolius* L.) has been the predominant grain legume in Western Australia (WA), producing grain totalling 500,000-1,000,000 t yr^{-1} (French and Buirchell, 2005). The majority of lupins in WA are grown in the northern wheatbelt (van Gool, 2009). Due to a lack of vernalisation-insensitive long season varieties adapted to the WA environment (Berger et al., 2012), lupin has not been widely incorporated into farming systems in the southern-wheatbelt (Howieson and O'Hara, 2008), where lupins may benefit from a longer growing season and lower evaporation rates. It is important to understand the yield potential of lupin in this region to develop sustainable agricultural systems. Furthermore, matching crop phenology with climate conditions, through combining improved varieties and sowing dates, is one of the key factors to improve and stabilize crop production (Farré et al., 2002). The optimum combination of cultivars and sowing date for lupin should be identified to match growth to available water in the southern wheatbelt of WA. Because of our lack of access to vernalization-insensitive long season varieties, this is not feasible at the moment. However the implications of such a crop can be explored using simulation modelling, which can be used to ask, if such varieties existed, how would they perform in the southern agricultural region?

The objectives of this paper are to use a simulation modelling approach to investigate lupin production potential in the southern wheatbelt of WA and examine the patterns of lupin yield responses to changes in sowing dates and varieties.

Materials and Methods

Study locations

Six study locations, Badgingarra, Eradu, Mullewa, Manjimup, Katanning and Lake King, were selected (Table 1). A major consideration for site selection is the contrasting rainfall conditions. Badgingarra, Eradu and Mullewa are located in the high, medium and low rainfall zones in northern agricultural region of WA, respectively; while Manjimup, Katanning and Lake King are located in the high, medium and low rainfall zones in southern agricultural region, respectively.

Table 1 Details of study sites

Site	Lat. (°S)	Lon. (°E)	Annual mean temperature	Growing season mean temperature[1]	Annual rainfall	Growing season rainfall
Badgingarra	30.40	115.55	18.9	16.0	549	496
Eradu	28.65	115.05	20.1	17.2	356	314
Mullewa	28.54	115.51	20.1	16.8	342	281
Manjimup	34.33	116.00	15.2	13.0	934	837
Katanning	33.67	117.60	15.8	13.2	471	396
Lake King	33.09	119.69	16.5	13.9	337	253

[1]Growing season is from May to October

Model parameterisation and application

APSIM (Holzworth et al., 2014) was used to evaluate lupin productivity and agricultural management options. Model parameters were determined using lupin data obtained from historical variety trials conducted at the experimental sites of Badgingarra in 2006, Eradu in 2005 and Mullewa in 2005 (Berger et al., 2012). Four lupin cultivars, namely Mandelup, Quilinock, Chittick and Jindalee were evaluated, which differ in maturity (Berger et al., 2012). All the data were used to derive crop model parameters through iterative adjustments. Model performance was evaluated by comparing observed and simulated values in terms of the root mean squared error (RMSE) and the coefficient of determination (r^2).

The tested model was then used to simulate lupin yield at the six study sites (Table 1) to explore lupin yield performance at the southern agricultural region of WA, using cv. Jandalee (late maturity). The model was also used to investigate the effects of cultivar and sowing date on lupin production to identify the potential agronomic management alternatives at the three southern locations. Two lupin cultivars (early maturity: Mandelup; late maturity: Jindalee) were selected to sow on 20 April and thereafter at 10 day intervals until 20 June over the period of 1961-2013, assuming opening rains occurred for each sowing window. Aside from maturity all other parameters were the same for these two cultivars.

Results

Model performance

Both flowering time and lupin grain yield were reasonably well predicted. APSIM accounted for 98% of variations for flowering time and 97% for grain yield (Figure 1). The RMSE for flowering time and grain yield were 3.0 days and 136.1 kg ha^{-1}, respectively.

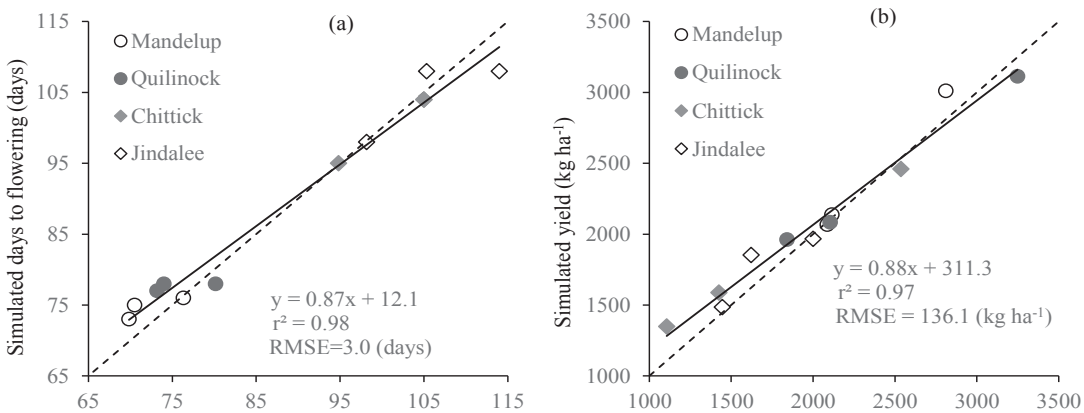

Fig. 1 Relations between simulated and measured days to flowering (a) and yield (b) for four lupin cultivars at Badgingarra, Eradu and Mullewa.

Variability in lupin yield at six sites

Figure 2 shows the cumulative probabilities of simulated yields of lupin with cv. Jindalee sown on 10 May each year between 1961 and 2013 at six locations. In the high rainfall zone, due to lower solar radiation as a result of higher rainfall during lupin growing season and lower latitude, the range and average of simulated lupin yield at Manjimup in the southern agricultural region of WA was smaller than that at Badgingarra in the northern agricultural region. In the medium rainfall zone, simulated lupin yield at Katanning in the southern

agricultural region showed less variation than that at Eradu in northern agricultural region, as indicated by the steeper slope of the cumulative probabilities. At Katanning about 90% of year had yields larger than 2000 kg ha^{-1}, while at Eradu only about 65% of years had this amount. In the low rainfall zone, simulated yield was larger than 2000 kg ha^{-1} in less than 20% of years at Mullewa, while it was larger than 2000 kg ha^{-1} in more than 40% of years at Lake King in the southern agricultural region. In the medium and low rainfall zones in the southern agricultural region, the cooler growing season temperature together with average higher rainfall increased lupin productivity with a fairly high probability. On average, simulated lupin yield in the southern two rainfall zones was 15% higher than the two northern rainfall zones.

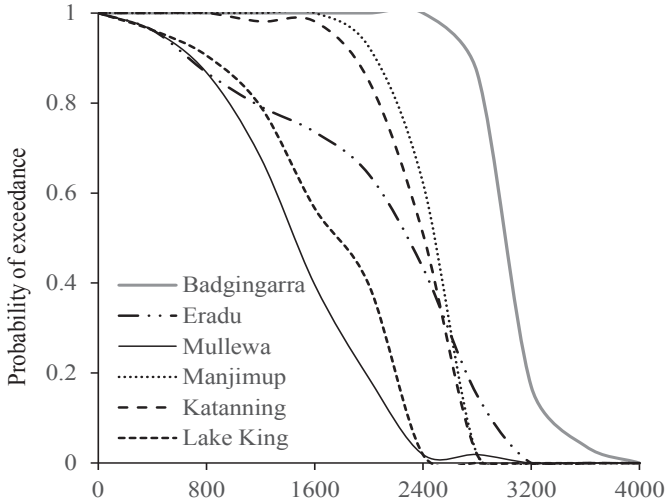

Fig. 2 Cumulative distribution of simulated lupin yield for cv. Jindalee at six sites (Badgingarra and Manjimup at high rainfall zone, Eradu and Katanning at medium rainfall zone, Mullewa and Lake King at low rainfall zone).

The response of lupin yield to the combined changes in sowing date and variety

A marked cultivar × sowing time interaction was evident at all three locations in the southern wheatbelt (Fig. 3). At Manjimup (high rainfall zone), lupin yield of the early-maturity variety increased with delayed sowing. However, for a late-maturity cultivar to achieve higher yield it needed to be sown earlier than 30 May (Fig. 3a). This is because the late-maturity cultivar could take advantage of ample water resources in the high rainfall zone. While at Katanning in the medium rainfall zone, there was a crossover of lupin yield between early-maturity and late-maturity cultivars in the mid-May, indicating that late-maturity cultivars should be sown before mid-May and cultivars with early maturity should be sown after then (Fig. 3b). In the low rainfall zone, early-maturity and late-maturity cultivars had little difference if they were sown early, but varieties with early maturity should be considered if sowing was later than late April (Fig. 3c).

Conclusions

A preliminary test of the APSIM model showed that it could reasonably reproduce lupin development and yield in the study area. Simulation results using the tested model combined with historical climate data showed that, if a lupin cultivar that was grown in northern agricultural region was sown in southern agricultural region, on average it would have higher grain yield. In the medium and low rainfall zones of the southern agricultural region, yields increase because the growing season is longer and temperatures are lower. In the high rainfall zone, the benefit of this effect was somewhat offset by the lower solar radiation. Overall in the high and medium rainfall zones in southern agricultural region of WA, higher yields would be obtained from late-maturity cultivars when sown before late April if opening rains occur. In low rainfall zone, sowing in early April was preferable with either early- or late-maturity cultivars. This preliminary work suggests that breeders should pay attention to releasing lupin varieties that address longer growing season potential in areas such as southern WA. Further research should be performed to assess breeding of vernalisation-insensitive long season varieties, lupin agronomy, production and its balance with other crops in terms of economic and environmental performance.

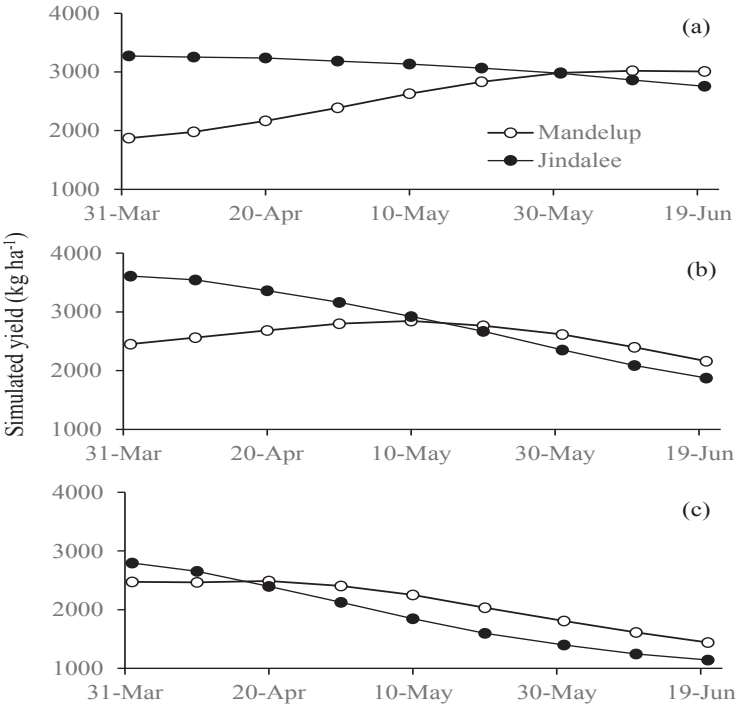

Fig. 3 Simulated lupin yield for cv. Mandelup (early maturity); cv. Jindalee (late maturity) under different sowing dates during 1961-2013 at Manjimup (a), Katanning (b) and Lake King (c).

Acknowledgement

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The residual N benefits of temporary intercropping field pea with wheat

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Abstract
Intercropping research in Australia has focussed on the productivity benefits in the year of the intercrop. However, cereal-legume intercrops may provide residual nitrogen (N) to subsequent crops. In a two-year field experiment at Cunderdin, WA, the residual N benefits of wheat-pea intercrops were examined. Treatments established in 2013 included (i) field pea monoculture var. Kaspa, (ii) wheat monoculture var. Mace, (iii) Wheat-pea intercrop, (iv) wheat-pea intercrop with the peas removed by selective herbicide in September, and (v) wheat-pea intercrop with the peas removed in October. No N fertiliser was applied to any treatment. The wheat monoculture yielded 2.6 t/ha with intercropped wheat yields reduced ($p<0.001$) by 44% (Sep removed peas) and 69% (Oct removed peas and full intercropped peas). There was additional soil N following both field pea and intercrop treatments. In 2014 the site was sown to wheat var. Mace. The wheat after wheat treatments received either no N fertiliser or 100 kg N/ha. All other treatments received no fertiliser N. Wheat yield responded to the previous crop ($p<0.001$) with the highest yields for wheat following wheat with fertiliser N (4.4 t/ha); intermediate yields for wheat after peas or intercrop, regardless of duration at 3.2 t/ha and lowest for wheat after wheat with no fertiliser N (1.9 t/ha). Protein content also varied and reflected the available soil N. Wheat-pea intercrops were as good as a pea crops at providing additional N to subsequent crops. They warrant further investigation as potential components of sustainable cropping rotations.

Introduction
Intercropping, growing two or more crop species simultaneously in a field, is widely practiced in low input farming systems. However, there has only been limited intercropping research in Australia (Fletcher et al. 2015). Most of this research has focused on the productivity of the intercrop itself with no research on the residual effects of intercrops on the productivity of subsequent crops in rotation. Annual cereal-legume intercrops can increase cereal yields in the intercrop season due to the benefit of N fixation from the legume to the cereal component (Hauggaard-Nielsen et al. 2009b). It is possible that the increased soil nitrogen concentration resulting from N fixation following the legume crop will continue into subsequent crops (Hauggaard-Nielsen et al. 2009a).

A new approach, "temporary intercropping of legumes and cereals" was examined by Tosti and Guiducci (2010). This is where a legume is sown with a cereal, but then killed before maturity so that N becomes available to the cereal. Tosti and Guiducci (2010) used cultivation to kill a faba bean crop and incorporate the residue. The appropriate time to terminate the legume crop would be determined by estimating legume growth and subsequent N fixed, likely rainfall to maturity of the wheat crop for the legume DM to break down to assist the intercrop wheat and early enough to ensure no major resource competition with the wheat crop. It is likely that the legume crop would have to be killed before the start of wheat flowering when rates of water use typically increase. Such an approach has not been examined in Australia.

This paper reports the results of a two year field experiment in WA that tested the hypothesis that the yield of wheat grown after a wheat/field pea intercrop will be greater than wheat grown after wheat and similar to the yield of wheat grown after a sole field pea crop. A secondary hypothesis was that the N supply to the second year wheat crop from temporary pea intercrops (killed with herbicides in spring) would be similar to intercropped peas grown for yield (full season intercrop), but crop competition would not reduce wheat yields in the first year.

Materials and methods
A two year field experiment was undertaken at the WANTFA long term cropping site near Cunderdin (31.64°S, 117.25°E) in WA. This site was a red sandy clay loam with moderate N fertility. In the first year of the experiment (2013) a range of monoculture crops and intercrop treatments of field pea var. Kaspa and wheat var. Mace were sown at 60 and 120 kg seed/ha, respectively (Table 1) on 11 June 2013. The intercrop

treatments were additive in design (i.e. 60 kg/ha of wheat seed and 120 kg/ha of field pea seed). Two of the three intercrop treatments were sprayed with a selective herbicide (1.5ml/ha of Torpedo; ai Clopyralid 300g/L and Florasulam 50g/L) to kill the field pea during spring. No N fertiliser was applied in 2013. The experiment comprised a total of 6 treatments with 4 replicates in a randomised complete block design. Plot dimensions were 2.2 X 12m. Grain yields were assessed on 28 Nov 2013 from a 0.8 m^2 quadrat. Samples were split into wheat and field pea grain and oven dried to constant weight. Wheat grain was analysed for total N content using LECO combustion. These were converted to grain protein content (%) using a factor of 5.7. The whole plot was harvested with a small plot harvester with all residue retained.

Table 1. Outline of treatments used in experiment.

Treat-ment	2013			2014	
	Crop	Spraying of pea crop	N applied	Crop	N applied (kg N/ha)
1	Pea	Not sprayed	0	Wheat	0
2	Pea – wheat intercrop	Sprayed 5 Sep	0	Wheat	0
3	Pea – wheat intercrop	Sprayed 3 Oct	0	Wheat	0
4	Pea – wheat intercrop	Not sprayed	0	Wheat	0
5	Wheat	-	0	Wheat	0
6	Wheat	-	0	Wheat	100

In 2014 the whole site was sown to wheat var. Mace on 16 May 2014. The wheat monoculture 2013 treatment was split into two treatments that received either 0 or 100 kg N/ha as urea on 10 June 2014 (2-3 leaf stage). All other treatments received no N fertiliser. Grain yields were assessed on a 1.2m^2 quadrat from each plot on 19 November 2014. Grain samples were analysed for total N content using LECO and converted to protein content (%) using a factor of 5.7.

Soil samples were taken for the 0-20 cm layer on 5 September and 28 November 2013 (harvest); and 0-20 and 20-40 cm layers on 20 May 2014. Samples were analysed for mineral N (Ammonium and Nitrate). This was converted to kg/ha using an assumed soil bulk density of 1.6 g/cm^3.

All variables were analysed using a one-way Analysis of Variance in Genstat with means separation using Fischer's Protected least significant difference (LSD; $\alpha = 0.05$). Where treatments did not include a particular crop that treatment was not included in the ANOVA. Thus, in 2013 the monoculture pea crops were not included in the analysis of wheat yield or protein and the monoculture wheat crops and wheat-pea intercrops sprayed on 5 Sep. were not included in the analysis of field pea yield.

Results

Growing season rainfall (Apr-Oct) in 2013 was 229 mm which is much less than the long term average of 278 mm. Rainfall was particularly low in both April and June when 4 mm fell in both months compared to long term averages of 24 and 57 respectively. The 2014 growing season rainfall of 320 mm was much greater than the long term average particularly in Apr and May when a total of 120 mm of rain fell.

2013 Crop performance

The wheat monoculture crop yielded 2.6 t/ha and the field pea monoculture crop yielded 1.7 t/ha (Table 2) in 2013. Due to resource competition, wheat yields in the intercrops were reduced compared to the wheat monoculture ($p<0.001$). In the temporary intercrop where the field peas were sprayed out early (5 Sep) the wheat yield was 1.5 t/ha. This was greater than for a late temporary intercrop (3 Oct spray) or a full intercrop (field peas not sprayed out) which yielded an average of 0.8 t/ha. The wheat protein content was 10.6% as a monoculture crop. This increased markedly ($p<0.001$) to ~13.0% when grown as part of an intercrop. Resource competition also resulted in field pea yield being reduced ($p<0.01$) in the intercrop to 0.5 t/ha. Some field pea grain growth (0.2 t/ha) had occurred in the late temporary intercrop before it was sprayed out.

Table 2. Crop yields (t/ha) and protein contents of wheat (%), and soil (kg/ha) mineral N across the two years.

Treat-ment	2013					2014			
	Soil N (0-20cm)	Pea Yield (t/ha)	Wheat Yield (t/ha)	Wheat Protein (%)	Soil N (0-20cm)	Soil N (0-20cm)	Soil N (20-40cm)	Wheat Yield (t/ha)	Wheat Protein (%)
Date	5 Sep	28 Nov	28 Nov	28 Nov	28 Nov	20 May	20 May	19 Nov	19 Nov
1	22.4	1.67	-		29.6	33.5	39.8	3.47	9.1
2	23.6	-	1.49	12.6	28.0	32.7	32.7	2.96	9.0
3	23.6	0.17	0.73	13.3	21.6	38.3	50.3	3.21	9.8
4	23.6	0.45	0.93	13.0	12.0	40.7	39.9	3.19	9.0
5	17.6	-	2.60	10.6	8.4	32.2	31.14	1.94	9.0
6								4.38	9.6
Sig (p<)	n.s.	0.01	0.001	0.001	n.s.	n.s.	n.s.	0.001	n.s.
LSD (α = 0.05)		0.66	0.52	1.28				847	

2014 Crop performance

Growing season rainfall (Apr-Oct) in 2014 was 270 mm. The highest wheat yields (4.4 t/ha) were achieved when wheat was grown after wheat and supplied with 100 kg N/ha as fertiliser. The lowest yields (1.9 t/ha) occurred when wheat followed wheat but without any N fertiliser supplied. This indicated that N supply was severely limiting yield. The yields of wheat after field peas or intercrop (regardless of duration) all fell between these yields and were not different to each other. There were no differences in wheat protein content across the treatments (Table 2).

Available Soil N measurements

There were no differences in soil mineral N at any date (Table 2). However, there was a trend at the harvest of the 1st year (28 Nov) for the pea monoculture and intercrop treatments to have higher soil N than the wheat treatment ($p = 0.121$). This was supported by orthogonal contrasts that found no difference between the soil N in the intercrops (Treatments 2, 3 and 4) and the sole pea crop (Treatment 1); but that treatments containing peas (Treatment 1, 2, 3 and 4), either as a monoculture or an intercrop, had more ($p<0.05$) soil mineral N than the wheat (Treatment 5).

Discussion

In 2014 there was a strong growth response of wheat to the intercrops and monoculture pea treatments compared with the wheat after wheat treatments with no N fertiliser (Figure 1). However, the strongest growth response was for wheat after wheat with 100 kg N/ha fertiliser (Table 2). The intercrops were as good as the monoculture pea crops in supplying residual N. Although, the soil N results were inconclusive (Table 2), the extra wheat growth and yield obtained in 2014 with 100 kg N/ha suggested that the residual benefits of the pea crops and intercrops over the wheat after wheat unfertilised crop (Table 2) was due to an increased soil N. Additionally, the protein levels were all low (<10%) indicating that N was limiting yield (Table 2). It was likely that mineralisation of organic N occurred during the cropping season which was not measured.

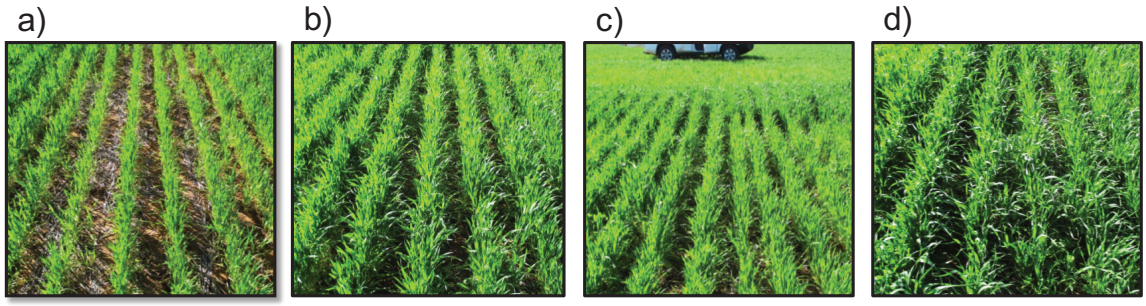

Figure 1. Growth of wheat on 1 Aug 2014. Wheat grown after: a) Wheat with no N fertiliser, b) field pea, c) wheat-pea intercrop, and d) wheat with 100 kg N/ha (2014).

There was a wheat yield penalty in the first season from growing these intercrops. This was due to the increased resource competition from the field peas when they were grown in intercrops (Table 2). The low land equivalent ratio (LER) of 0.64 (data not shown) is much less than for other intercropping experiments in Australia (Fletcher et al. 2015). The LER is a measure of the relative amounts of land needed to grow an equivalent amount of field pea and wheat as if they were grown as sole crops. A LER less than 1 indicates that more land is required. Our low LER indicated that there was no benefit and a likely overall productivity loss in the intercrop in the first year. This may be related to the intercrops being additive and not substitutive.

There was a large wheat yield decrease in the intercrops in 2013 compared with the wheat monocultures, but this was made up for by an increase in wheat yields in the second season (table 2). Across the two seasons mean total wheat yields were 4.3 t/ha in all of the intercrop treatments and the wheat after wheat treatment with no fertiliser N (treatment 5). However, the total yields of wheat after wheat with 100 kg N fertiliser (treatment 6) were much greater (7.1 t/ha; $p<0.001$). Even though the wheat yields decreased in the intercrops in 2013 the protein content increased (Table 2), this can be interpreted in two ways. Firstly, the N_2 fixation by the field pea component of the intercrop supplied extra N to the wheat and increased protein content. Alternatively, the increase in protein content may be due to the smaller grain yields with a natural dilution of N. The latter is more likely as an analysis of total protein yield found that wheat crops yielded more wheat protein/ha than the intercrops (data not shown).

It was possible to reduce the loss in wheat yield by spraying out the field peas in September (Treatment 2). In the second year this treatment produced similar wheat yields to those following the other intercrops and the pea monoculture. Spraying the peas out early in year 1 may be a useful strategy to obtain a residual benefit in year 2 while still obtaining a good wheat yield in year 1. Perhaps, if the field peas had been sprayed out earlier the competitive effects would have been less. The 1st year wheat yields in temporary intercropping treatments are not consistent with those of Tosti and Guiducci (2010). Their temporary intercrops did not reduce wheat yields compared with monocultures. This may be because we sprayed our pea crops, whereas they incorporated their pea crops. Thus, in their experiment the field pea residues would have broken down much quicker. Alternatively, we delayed the spraying of the pea crop too late. They incorporated their legume crop at wheat stem extension, whereas we waited until wheat anthesis. Research with dual purpose crops has shown that wheat crops can recover from grazing up until the beginning of stem elongation (GS 30) (Harrison et al. 2011). This may have been a more appropriate time to spray the peas in our experiment. Furthermore, Tosti and Guiducci (2010) used faba bean, which may be less competitive than the field peas.

Overall, our experiment demonstrated that full and temporary intercrops are an innovative strategy that can supply N to subsequent crops in a rotation without completely forgoing the opportunity to grow wheat. Temporary intercrops warrant further investigation to identify how best to manage the competition between the legume and wheat. The appropriate legume species, cereal varieties, sowing rates and dates of the two components, and the best time to kill the legume, all need to be identified.

Acknowledgement
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A desktop analysis of the economics of fixed N in Australian dryland cropping rotations

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Abstract

Grain legumes have played an important part in Australian agriculture providing an economic yield, a weed/disease break and supplying nitrogen (N) to the cropping system via fixing atmospheric N. However, the potential opportunity cost (lost profit for not growing other crops) of growing legumes, means fixed N is not necessarily "free". Furthermore, fertiliser may be a cost-effective alternative source of N. A desktop analysis was conducted to quantify the economic value of fixed N in three dryland legume-wheat rotation systems (WA-lupins, Vic-field pea, and NSW- chickpea) across Australia, by comparing legume-wheat to wheat-wheat rotations over 100 seasons with the APSIM simulation model. Scenarios included a range of soil N and fertiliser N rates applied to wheat. The economic values of the two rotations were analysed using a simple economic framework that accounted for commodity price and the value of residual fixed N. The results showed that the biggest driver of profitability to grow a grain legume crop was the economic return from the legume grain. Residual fixed N only accounted for a small component of the economic return except when fertiliser N was not applied to subsequent wheat crops. The value of residual fixed N was low because most of the fixed N was removed with the harvested legume grain and under current prices fertiliser N was a cheaper alternative. Therefore, farmers should integrate grain legumes in their rotations only if they are profitable compared to alternative crops, in terms of commodity price and weed/disease benefits.

Key words

Fertiliser N, grain price, grain legume, profit, pulses

Introduction

Soil nitrogen (N) is a common limiting factor to crop growth and yield. Ensuring that crops have access to sufficient N is central to productive farming systems (Sinclair and Rufty 2012). Historically, much of the N supplied to cropping systems came from the biological N fixation derived from the symbiotic relationship between legumes and rhizobia. Measurements have shown that quite large amounts of N can be fixed by legume crops. For example, the mean amount of measured N fixed by lupin, chickpea, field pea and faba bean is 136, 40, 84 and 90 kg N/ha respectively (Unkovich et al. 2010). Despite this, there has been a decline in the area of some legume crops in Australia, such as the area sown to lupin decreasing from 1.3 to 0.7 M ha between 1995 and 2011 (ABARES). In contrast, recently fertilizer N has been widely used in cropping systems and become a cost-effective alternative to supply N to crops. It is important to understand the triggers for such changes for developing profitable and sustainable agricultural systems in the future.

Biological N fixation has often been treated as a source of "free" N in cropping systems. However, when growing a legume crop there is a potential opportunity cost, i.e. the profitability that is foregone for not growing another crop, which needs to be considered. Taking account of the opportunity cost is vital in determining the economic value of fixed N. There is often a yield benefit to cereal crops grown after legumes (e.g. Seymour et al. 2012), which also needs to be considered. However, quantifying the economic value of fixed N to a cropping rotation is difficult. If the total economic value of residual fixed N following a legume crop and its contribution to following cereal crop is less than the opportunity cost, fixed N will not be a contributor to increased profitability. Here we report the results of a desktop analysis that quantified the economic contribution of legume fixed N to dryland cropping rotations in Australia. We used the APSIM simulation model (Holzworth et al. 2014) and constructed a bio economic framework to account for the yield benefits to a cereal following a legume crop, the value of the fixed N, but also the opportunity cost associated with growing a legume crop instead of a cereal.

Materials and methods

We constructed hypothetical cropping rotations at three representative sites throughout the Australian grain belt (Table 1). For each site simulations were run for 100 years (1912-2012) for both a wheat-wheat rotation and a legume-wheat rotation using APSIM, which has been shown to be able to adequately model the amount of N fixed by legume species (Chen et al. 2015). Standard sowing and harvesting rules were used for each crop. Various starting soil N and fertiliser N applied to wheat at sowing were simulated (Table 1). But no fertiliser was applied to the legume crops.

Table 1. Locations and biophysical/economic variables applied in each analysis

	Dalwallinu, WA	Birchip, Vic	Moree, NSW
Legume crop	Lupin	Field pea	Chickpea
Starting soil N (kg N/ha)	20, 80	20, 80	25, 75, 150
Fertiliser N applied to cereal (kg N/ha)	0, 50, 100, 150	0, 50, 100, 150	0, 50, 100
Fertiliser N price ($/kg N)	1.00, 1.50, 2.00, 2.50, 3.00	1.00, 1.50, 2.00, 2.50, 3.00	1.00, 1.50, 2.00, 2.50, 3.00
Legume grain price ($/t)	200, 250, 300, 350	250, 300, 350, 400	200, 300, 400, 500

A simple economic framework was applied to each rotation taking into account both the value of grain from both crops and the extra N in the cropping system following the legume crop. The calculation of N in the system also included the saved N (N not applied) by the legume crop compared with wheat. Economic scenarios included various legume prices (depending on crop) and three fertiliser N prices ($1.00, $2.00, and $3.00/kg N) with a fixed wheat price ($300/t). For comparison, mean fertiliser N prices between 2003 and 2013 were $1.24/kg N with a range from 79 c/kg N to $1.91/kg N (ABARES). Fertiliser N price was used to calculate the cost of fertiliser N applied to the wheat crops but also the extra N contributed to the system from the N fixation of the legume crops. Residual fixed N from the legume was calculated as the difference in N in the cropping system at the beginning and end of the two year rotation. The mean difference in profitability between the two rotations over two years was used to evaluate the economics of fixed N.

Results

Birchip

Simulated mean yields for wheat and field pea were 2.6 t/ha and 2.3 t/ha, respectively. With a low starting soil N, the field pea crops fixed a mean of 99 kg/ha and removed 83 kg N/ha in grain, leaving a residual N benefit of 6 kg N/ha. With a high starting soil N, the field pea crops fixed a mean of 69 kg/ha and removed 83 kg N/ha in grain, leaving a residual N deficit of 14 kg N/ha. The actual value of this residual N depended on the price of N. Field pea-wheat rotations were generally more profitable than wheat-wheat rotations (Figure 1). The biggest driver of profitability were changes in the price received for field pea. At a low field pea price of $250/t many of the field pea-wheat rotations had lower returns than a wheat-wheat rotation. Under all scenarios where the field pea price was $400/t a field pea-wheat rotation had the highest return. The amount of N applied to the wheat crop was also a big determinant of profitability. As more N was applied to wheat crops the value of fixed N decreased and therefore the relative profitability of this rotation fell. N fertiliser price was only a small driver of the difference in returns between these two rotations.

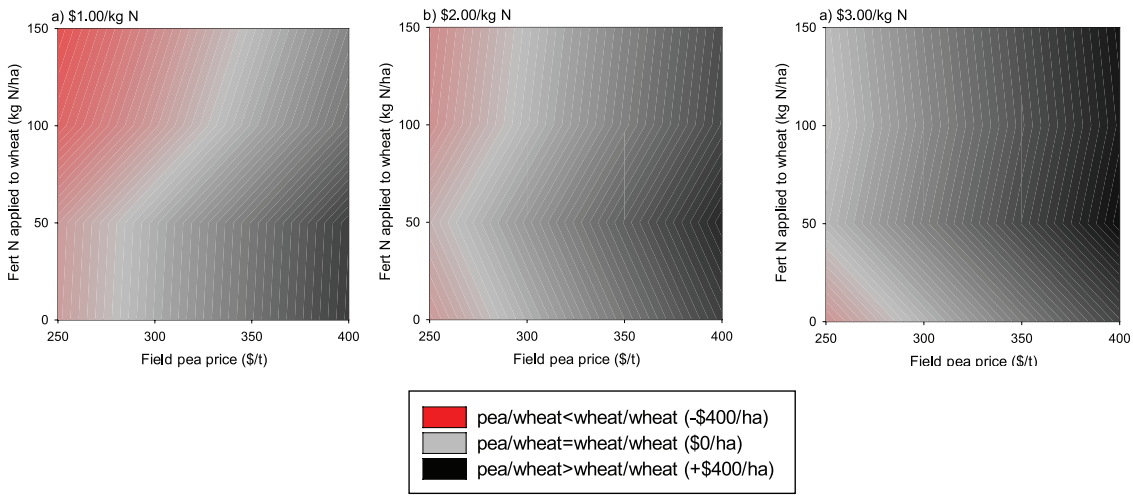

Figure 1. Effect of applied fertiliser N, Field pea price and fertiliser N price on difference in profit from field pea-wheat rotations and wheat-wheat rotations at Birchip for a low N soil (20 kg N/ha).

Dalwallinu

Simulated mean yields for wheat and lupin were 2.7 t/ha and 1.3t/ha, respectively. With a low starting soil N, the lupin crops fixed a mean of 113 kg/ha and removed 71 kg N/ha in grain, leaving a mean residual N

benefit of 42 kg N/ha. With a high starting soil N, the lupin crops fixed a mean of 95 kg/ha and removed 71 kg N/ha in grain, leaving a mean residual N benefit of 24 kg N/ha. The biggest driver of profitability was changes in the amount of fertiliser applied to wheat crops. In most situations with no fertiliser lupin-wheat rotations were more profitable than wheat-wheat rotations (Figure 2). However, when any rate of fertiliser N was applied the lupin-wheat rotations were less profitable than wheat-wheat rotations, especially with low fertiliser N prices (Figure 2a). Lupin prices had only a small impact on relative profitability. Overall, N fertiliser prices needed to triple to $3.00 kg/N to make a marked change in the return difference (Figure 2c).

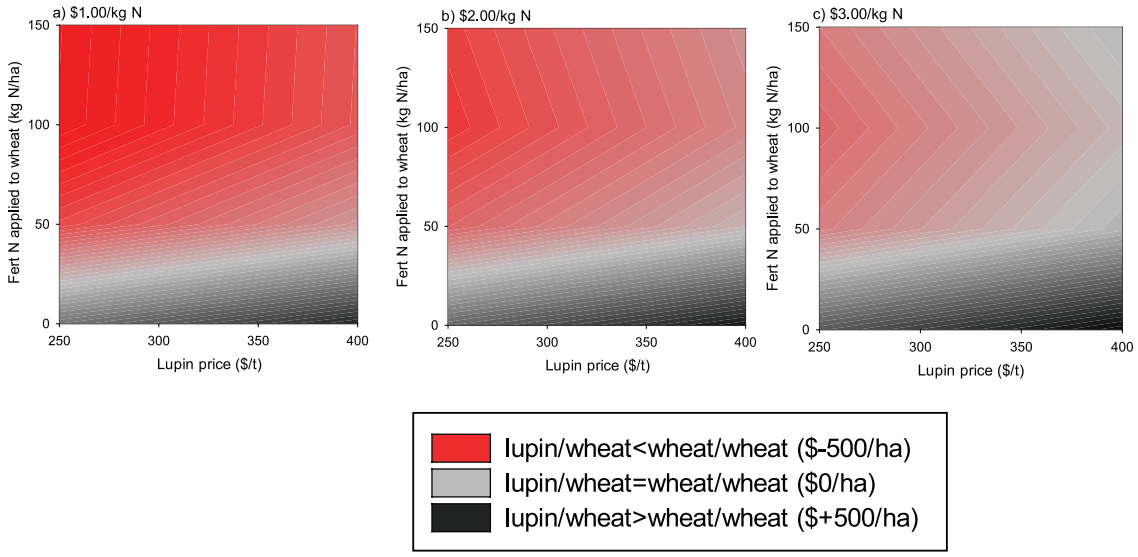

Figure 2. Effect of applied fertiliser N, lupin price and fertiliser N price on difference in profit from lupin-wheat rotations and wheat-wheat rotations at Dalwallinu for a low N soil (20 kg N/ha).

Moree

Simulated mean yields for wheat and chickpea were 2.6 t/ha and 1.6t/ha, respectively. With a low starting soil N, the chickpea crops fixed a mean of 66 kg/ha and removed 57 kg N/ha in grain, leaving a mean residual N benefit of 9 kg N/ha. With a medium starting soil N, the chickpea crops fixed a mean of 39 kg/ha and removed 57 kg N/ha in grain, leaving a mean residual N deficit of 18 kg N/ha. With a high starting soil N, the chickpea crops fixed a mean of 25 kg/ha and removed 96 kg N/ha in grain, leaving a mean residual N deficit of 71 kg N/ha. In most situations where chickpea price was $300/t or greater, the chickpea-wheat rotation was more profitable than a wheat-wheat rotation (Figure 3). The difference in return between the two rotations was equally sensitive to both chickpea price and the amount of N fertiliser applied to wheat. There was very little change in the difference in return between the rotations when fertiliser price doubled to $2/t (Figure 3b). However, there was a shift in favour of the chickpea-wheat rotation when fertiliser N price tripled to $3/t (Figure 3c).

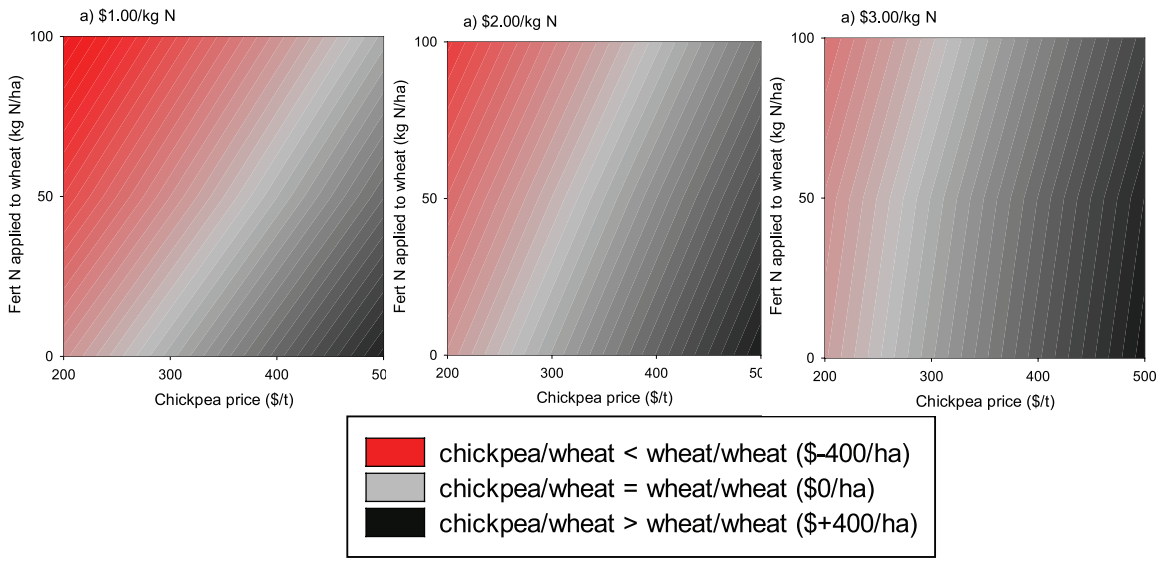

Figure 3. Effect of applied fertiliser N, chickpea price and fertiliser N price on difference in profit from chickpea-wheat rotations and wheat-wheat rotations at Moree for a medium N soil (75kg N/ha).

Discussion

The value of fixed N from the legume component of these rotations was small compared to the economic return from legume grain. There are 2 reasons to explain why the economic value of fixed N was low. The first was that under current prices fertiliser N was a cheaper alternative than fixed N. This was highlighted by the relative insensitivity of economic return to fertiliser N price (which also determined the value of fixed N) (Figures 1-3). This was further highlighted by the response of relative to applied fertiliser N. When no fertiliser N was applied to wheat crops any residual N from the legume had a large effect on profitability due to the extra wheat yield. This was most pronounced for the lupin-wheat rotation in WA (Figure 2) due to the larger amounts of residual N following lupins compared to the other two legumes. However, when N fertiliser was applied the lupin rotations were less profitable. The second reason was that a large proportion of fixed N was contained in legume grain, which was removed from the system after harvest of the legume crop and therefore was of no value to following crops.

The difference in return was always sensitive to legume grain price. This highlights the importance of the opportunity cost for growing (or not) these legumes. In some situations there was a large opportunity cost (e.g. Figure 2) and the legume-wheat rotations had a lower return than the wheat-wheat rotations. While in other some scenarios there was no or only a small opportunity cost (e.g. Figure 1) and the legume-wheat rotations had a higher return than the wheat-wheat rotations.

Conclusion

We are not advocating for or against including legumes in crop rotations in Australia, but rather analysing the possible economic values of N fixed by legumes. If they are profitable (based on yield and commodity price) compared with other alternative crops farmers should include legumes in their rotations. For all three rotations simulated residual N benefit following a legume crop was only a minor contributor to profitability. While fertiliser prices remain relatively low fixed N should not be a major driver in the decision to grow a legume or not. Our analysis did not consider the other benefits provided by legume crops in crop rotations such as weed and disease breaks. These considerations may be important drivers in the decision to grow a legume break or not. However, once the decision to grow a legume has been made then the amount of residual N following that legume crop will need to be considered in the N fertiliser applied to subsequent non-leguminous crops.

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Targeting the subsoil to better manage acidity spatially

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Abstract
Subsoil acidity is common in Western Australia (WA). However, historical lime trials have focussed on ameliorating topsoil acidity only. While soil pH is a useful measure of acidity, it has rarely been coupled with potential crop yield to estimate the yield gap (the difference between actual yield and the water limited potential yield). This is required to understand by how much acidity is constraining yields and to target lime application. The relatively low yield increase in the historical lime trials (14%) would likely have been greater if the subsoil was ameliorated and lime use was targeted to severely constrained sites. The yield increases that could occur with full amelioration can be simulated using APSIM by adjusting the ability of roots to grow through acid layers. Increases in yield from lime application are dependent on the soil type, depth of acidity, severity of acidity and seasonal conditions. We use soil maps, yield maps, geophysics and point sampling to diagnose the acidity constraint and extrapolate to areas across the paddock. With this knowledge, lime application could be targeted to increase the lime-use efficiency (kg grain increase per tonne of lime applied). We use a case study paddock from a farm in Bodallin WA to present the methods for diagnosing the subsoil acidity and the gain from targeted lime application. In one paddock the lime-use efficiency was doubled (104 to 200 kg/t) by reducing the limed area from 120ha to target 42ha of the most responsive, below-average yielding area of the paddock.

Keywords
Subsoil acidity, yield gap, root depth, APSIM

Introduction

Subsoil acidity is common in Western Australia (WA) with 45% of the wheatbelt with a pH ($CaCl_2$) less than 4.8 in both the 0.1-0.2m and 0.2-0.3m layers (Gazey et al. 2013). However, historical lime trials in WA have only ameliorated the topsoil. This resulted in the pH increasing by 1 unit in the 0-0.1m layer, with much smaller increases (0.2-0.3 pH units) in the subsoil (Gazey et al. 2014). Average wheat yield increase after was lime applied at least one year previously, was 14% (Gazey et al. 2014). The low yield increases from liming in WA were due to the soil pH not always being a good indicator of the effect on crop yield. This was highlighted by the yield in the unlimed treatments having greater than 75% of yield potential in 40% of the cases in the DAFWA lime trial (Gazey et al. 2014), despite having a pH of <4.8. The yield gap may have provided more insight into determining how severely the acidity was in constraining the yields than just a pH profile.

Greater increases in subsoil pH and crop yield may be possible through higher rates of lime and better incorporation or movement of lime to depth. Farmers have begun trialling higher rates of lime with different methods of incorporation such as grizzly deep digger®, mouldboard plough, rotary spading, slotting and deep ripping. The likely gains from these incorporation methods in terms of soil pH and yield gains are unknown, as there are few trials and these have has insufficient time since the treatments were applied to test the impact on yield. Furthermore, it is difficult to infer the yield gains from these approaches on different soils, acid profiles and rainfall locations. As these amelioration methods are costly, a targeted approach based on likely yield gains may be valuable.

The effect of acidity can be estimated through APSIM modelling (Farre et al. 2010, Wong and Asseng 2007) by restricting root growth in different layers. The lower the pH the more the root growth is reduced. Yield gains from amelioration can then be estimated when the restriction to root growth is reduced or completely removed for different soil types, different acidic soil layers and severity of the acidity in these layers. To target areas for subsoil amelioration on a farm based on the greatest yield gains, we need to; 1) identify the soil types, 2) identify which soils layers are classed as acidic, 3) identify the severity of the acidity and

4) assign a likely yield gain to each area. The severity of the acidity was estimated from the root depth or percentage of potential yield for a known acid profile (inverse model approach). We demonstrate the process on a paddock from the eastern Wheatbelt WA.

The process

The case-study paddock is near Bodallin (31.266 S, 118.942 E) ~ 300km east of Perth WA. The farm has a long term (1913-2012) mean annual rainfall of 311mm with 228mm in the growing season (April-October). The yield monitor data was collected between 2004 and 2009 and the relative yield (RY) calculated for each 25m^2 pixel by dividing the measured yield by the water limited potential yield (Yw) (Oliver and Robertson 2013). Each pixel's performance was classified according to the relative yield: above-average (RY > 0.75), average (0.5<RY< 0.75) and below-average performance (RY<0.5).

1) Identify the soil types

A soil map of the paddock was originally created using Google Earth maps, farmer knowledge and our discussions with the farmer to assign the areas to a DAFWA soil group (Schoknecht 2002) (Fig 1a). The soil map was redefined (Fig 1d) after comparison of geo-located soil samples with the geophysics EM (Fig 1b) and Gamma (Fig 1c) based on Wong et al. (2010) (Table 1). The paddock was originally mapped as predominantly sandy soils classed as deep and shallow acid sands and deep yellow sand. The geophysics and soil sampling separated the sand classes into sand, sandy gravel and acid sandy gravel.

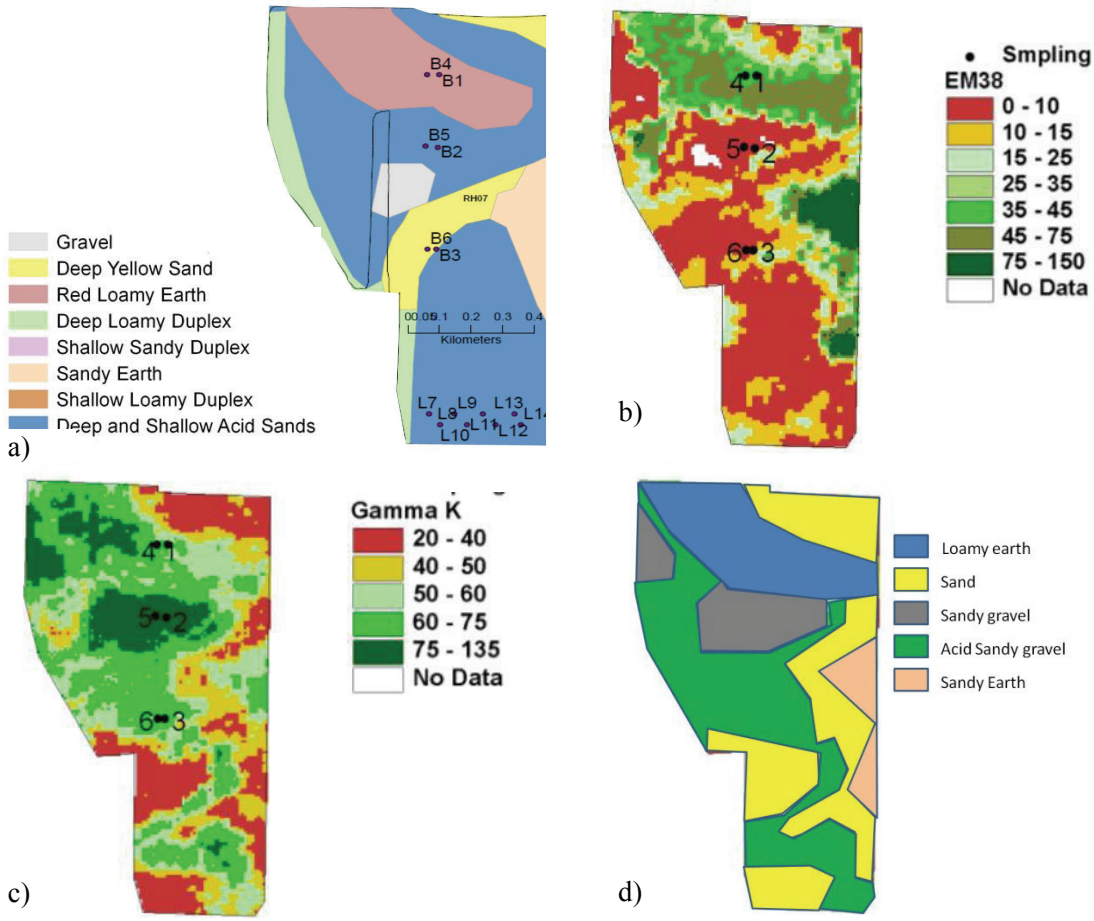

Figure 1. The data layers available for 'Roundhouse' paddock on the Bodallin case study farm a) farmer mud map, b) EM38, c) Gamma K radiometric and d) Soil map redrawn from geophysics. The deep sampling locations were in the different crop performance zones of above-average (B1, B4), average (B2, B5) and below-average (B3, B6).

2 &3) Identify the acidic soil layers and identify the severity of the acidity

Soil tests indicated that the sand, sandy gravel and acid sandy gravel had pH< 4.5 to a depth of 1.8m. The loamy earth was non acidic in all layers while there were no samples of the sandy earth.

We simulated the effects of acidity in APSIM by scaling the potential daily rate of root growth using an exploration factor (xf) for each soil layer. The value of xf ranges between 0 for no root growth to 1 for the maximum rate of root growth. We used a range of xf values (0.1, 0.2, 0.3, 0.5, 0.75 and 1). As acidity occurs in different layers of the soil profile, we varied xf in 0.1m layers of the soil profile between the 0-0.3m layer and 0-1.8m layer. We simulated acidity in the different layers for a sandy soil, sandy loam and a sandy duplex. The low plant available water capacity in the coarse texture sand causes greater percentage gains from amelioration than the sandy loam or duplex soils (Wong et al. 2007). The simulations used rainfall from over 100 years of climate data for the Bodallin weather station (1913-2012) to account for the variable response to amelioration. For example, ameliorating the 0-0.3m layers of a sand which is acidic to 1.8m with an xf =0.2, can, depending on seasonal conditions, change yield by -10% to 100% with a median of 32% yield increase. There were no relationship between yield gains with simple rainfall indices as it was also dependent upon the pattern of rainfall, stored soil water at depth and the requirement of deeper water to meet crop demand.

The severity of the acidity (xf) can be estimated using the relationship with relative yield or root depth (measured or inferred from water remaining in the profile) (Fig 2a,b). These relationships are specific to the soil type, pH profile and the year which the yield or root depth is measured. In this example yield values was taken from yield maps in 2008 and 2009 using both the soil sampling points and an average yield for that soil type (Table 1). The relative yield was calculated using yield potential of 2.20 t/ha in both 2008 and 2009. While root depth was not measured, it would be preferable as it can better differentiate between severities particularly at high xf values (Fig 2a,b).

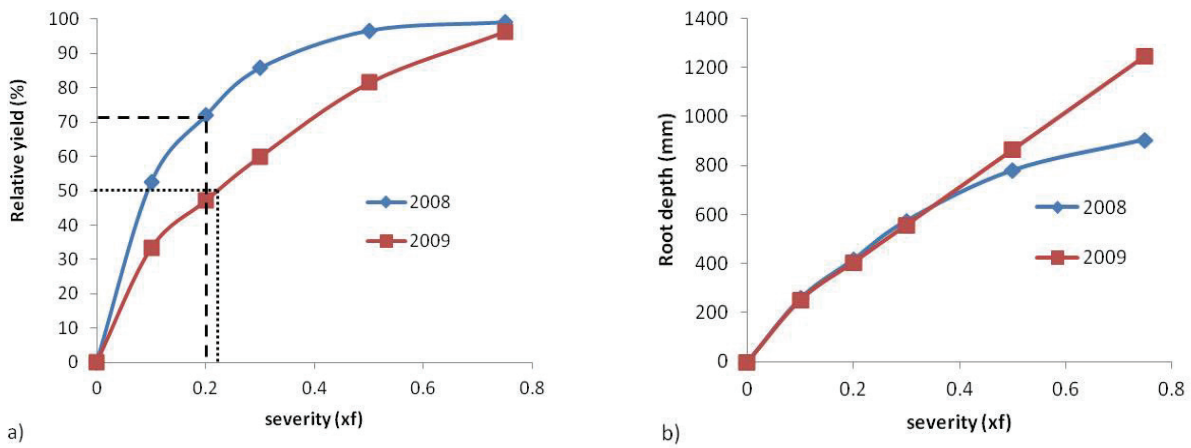

Figure 2. The modelled severity versus a) relative yield curves and b) root depth (mm) for an 0-1.8m acid profile in Bodallin in 2008 and 2009 with the measured relative yield at a point in the gravelly sandy earth of 0.71 in 2008 (---) and 0.51 in 2009 (….) which corresponded to a severity of xf=0.2.

4) Assign a yield gain to each area

Table 1. Soil properties (area, gamma, EMI, pH and Al), the average yield averaged for a soil type for 2008 and 2009, long term crop performance of that area which was used to estimated severity and yield increase for each soil type in a Bodallin paddock.

Soil type	Loamy Earth	Sandy Earth	Sandy gravel	Deep sand	Acid Sandy gravel
Area of paddock (ha)	18ha	6ha	12ha	42ha	42ha
Gamma	high (K>60)	Med (K50-60)	Very high (K>75)	Low (K<20)	high (K>60-75)
EMI	high (EMI>35)	High (EMI >75)	Low (EMI <10)	Low (EMI <10)	Low (EMI <10)
pH (CaCl2)	Neutral 7-8	No measurements	pH<4.5 in surface and 4.2 at depth	pH<4.5 in surface and 4.4 at depth	pH<4.5 in surface and 4.1 at depth
Al (CaCl2)	Not measured		Al >10ppm	Al <3ppm	Al 10-40ppm
Crop performance	Above-average	Above-Average	Average	Average	Below-average
Severity and modelled soil type	none	No measurements	0-1.8 xf =0.2 Sandy loam	0-1.8 xf=0.2 Sand	0-1.8m xf= 0.1 Sand
Average estimated yield increase	0%	0%	15%	32%	74%
Yield (t/ha)	2.4	2.05	1.6	1.58	1.1
Yield after amelioration	2.4	2.05	1.84	2.08	1.91

For each soil type (Fig 1d) a modeled soil type, pH profile and severity was assigned. The yield in each soil type was averaged over 2008 and 2009 using the yield maps. The average yield increase was estimated assuming the top 0-0.3m of the profile was ameliorated (Table 1) and the subsoil (0.3-1.8m) was still acidic.

Targeted lime application

We estimate the yield increase per tonne of lime applied (LUE) if different soil types were targeted for subsoil amelioration. In this analysis we assumed 4 t/ha of lime was applied, the yield was from the average of each soil in 2008 and 2009 and estimated yield increases from Table 1. We then reduced the area which lime was applied based on targeting the sandy soils, average and below average yielding sandy soils, then only those which have high yield increases (Table 2). By targeting only the acid sandy soil, the area for subsoil amelioration was only 34 ha, which double the LUE. This analysis does not take into account gains for ameliorating the topsoil nor the presence of other constraints once the acidity constraint is removed.

Table 2. Lime use efficiency for different targeted areas for liming.

	Amount of lime (t)	Area to lime (ha)	Yield increase (t)	Av paddock yield t/ha	Lime use efficiency (kg grain/ t lime)
All paddock	480	120	58	2.04	121
Sandy soil	408	102	58	2.04	143
Average and below average yielding sandy soils	384	96	58	2.04	152
Just deep sand and acid sandy gravel	336	84	55	2.02	164
Just acid sandy gravel	168	42	34	1.84	204
None	0	0	0	1.56	0

Conclusions

This methodology allows farmers to identify areas of a paddock or farm which may be most responsive to amelioration. A large proportion of a paddock may be non-responsive to lime or liming the subsoil. This is typical of several paddocks that we have studied in the wheatbelt. In the example shown in Table 2, liming the whole (480ha) paddock gave the same yield increase (58t) as liming only the 384 ha of average and below average yielding sandy soils. Liming only 336 ha of responsive sands (liming 50 ha less) only decreased the response by 3 t to 55 t. Targeted liming is likely to improve profits. The area to be targeted can be identified by using a range of spatial data including gamma and EMI maps, grower mud map and knowledge of the farm, and google map coupled with severity identification.

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Lessons from an evaluation of automated bay irrigation of pasture and fodder

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Abstract
Automation of surface (bay) irrigation is now a commercial reality. Automation provides increased certainty in irrigation management. However in the absence of appropriate decision support, key decisions, such as the scheduling of irrigations and irrigation duration, still rely on the skill of the irrigator. Over the 2013/14 irrigation season the authors evaluated the application efficiency achieved by farmers who had adopted automated bay irrigation, the trial involving 9 farms x 1 bay x multiple irrigations.

The results demonstrated that irrigation application efficiencies in excess of 90% are achievable and are being achieved through correct and precise management of the automated irrigation. Four of the farms evaluated are already operating at that level. For the others, strategies were identified that will raise their efficiency close to or above 90%. As well a number of not unexpected lessons relating to the irrigation management were learnt from the trial.

Key Words
Surface irrigation, application efficiency, irrigation duration, soil moisture

Introduction

An earlier study by the Cooperative Research Centre for Irrigation Futures (Smith *et al*., 2009 and Gillies *et al*., 2010) showed that average irrigation application efficiencies on bay irrigated dairy farms in the Goulburn Murray Irrigation District (GMID) in northern Victoria, were relatively low, at about 69%. It also showed that significant gains in efficiency (~20%) were possible by the simple expedient of doubling flow rates (to at least 0.2 ML/d/m width) and reducing irrigation durations. However at these higher flow rates and reduced times the irrigation performance is particularly sensitive to the irrigation duration or cut-off time.

Modernisation (automation) of the channel supply system in the GMID, under the government funded FoodBowl project, has responded to the work of Smith *et al*. (2009) and Gillies *et al*. (2010) by increasing the rate of supply available to growers from about 10 ML/d to near 20 ML/d, thus providing growers with the opportunity to increase their application efficiency. For growers seeking Federal Government support for on-farm efficiency improvements, GBCMA (2012) used the above work of Smith *et al*. (2009) and Gillies *et al*. (2010) to arrive at the recommended flow rate to the bay of 0.2 ML/d/m width.

A number of farms in the GMID have installed on-farm automation systems (as well as adopting the recommended higher flow rates), thus providing greater precision and certainty in the management of irrigation duration. Hence the objective of this study was to quantify the gains in application efficiencies possible through the use of optimally-managed, automated, high-flow bay irrigation and to demonstrate what can potentially be achieved from farms now supplied from a modernised irrigation supply system.

Evaluation Methodology

The GMID is located on an alluvial plain with soils that range from coarse sands deposited adjacent to former streams to fine textured, cracking clays from deposition of fine material remote from stream channels (Butler, 1950). Bay irrigation is the predominant irrigation method for pastures (perennial and annual) and fodder crops in the region. Annual average rainfall is between 350 and 500 mm, with annual average potential evapotranspiration of approximately 1300 mm.

The nine bay irrigation farms participating in the trial (Table 1) had invested in the Rubicon FarmConnect™ on-farm automation infrastructure, which in most cases had been in operation for a full irrigation season. The evaluation process used was similar to the Irrimate™ commercial irrigation evaluation process described by Dalton *et al*. (2001). Flow rates into the trial bays were inferred from measurements at the supply point to the farm. Irrigation advance and flow depth were measured at three points down each bay using Rubicon FloodTech depth sensors. Soil moisture was monitored continuously in each trial bay. All data were collected automatically and stored on-line.

Table 1. Details of the trial bays.

Farm	Bay Width (m)	Length (m)	Slope	Crop	Soil Type[1]	Flow Rate (ML/d)[3]
L	40	392	1:883	Lucerne	Goulburn loam (IV)	18 (0.45)
Q	45	450	1:635	Lucerne	Shepparton fine sandy loam (II)	10 (0.22)
P	50	400	1:390	Lucerne	Lemnos loam (III)	25 (0.5)
T	50	400	1:916	Maize	Moira loam (III)	14 (0.28)
I	50	548	1:426	Soybean	Youanmite loam (II)	21 (0.42)
M	80	340	1:682	Perm pasture	Not surveyed[2]	20 (0.25)
R	80	266	1:336	Perm pasture	Shepparton fine sandy loam (II)	14 (0.17)
D	68	294	1:723	Perm pasture	Fenihurst clay loam (IV)	10 (0.15)
G	42	310	1:508	Perm pasture	Mologa loam (III)	16 (0.28)

[1] Skene (1971) and Skene and Poutsma (1962)
[2] Most likely a group (IV) soil such as Goulburn loam, Goulburn clay loam or similar
[3] Figures in brackets are the flow rates per unit width (ML/d/m width)

The key performance measure used in the evaluations was the application efficiency which is defined as:

$$\text{Application efficiency (Ea)} = \frac{\text{volume (or depth) of water added to the root zone)}}{\text{total volume (or depth)of water applied to the bay)}}$$

and where losses occur principally as tail-water runoff and deep percolation though the root zone.

The model used in the evaluations was the Surface Irrigation Simulation Calibration and Optimization model (SISCO) developed by Gillies and Smith (2015). The model requires the physical characteristics of the bay, i.e. length, width, and slope of the bay, as well as the flow rate onto the bay, the soil infiltration characteristic and the resistance provided to the flow over the bay by the crop or soil surface. This latter characteristic is indicated by the Manning n, the roughness term in the well-known Manning flow equation.

SISCO is self-calibrating. In calibration mode, it estimates the soil infiltration parameters and roughness parameter (Manning n) from the measured inflow hydrograph and any combination of the advance data, runoff hydrograph, water depth measurements and recession times measured during the actual irrigation event. Once calibrated the model provides an accurate simulation of the given irrigation and was used to estimate the application efficiencies and the depths of infiltration along the length of the bay. It can also be used to determine the effect of varying the flow rate and irrigation duration (time to cut-off) and thus determine the preferred or optimum irrigation for the given conditions.

Results of Evaluations

The results from the evaluations, summarised in Table 2, demonstrate that application efficiencies in excess of 90% are indeed achievable and being achieved through correct and precise management of automated surface irrigation. Four of the farms evaluated in this study are already operating at that level. For four of the other five farms strategies were identified that will raise their efficiency close to or above 90%. On the remaining farm (farm G) soil limitations preclude any improvements in efficiency on the trial bay. Fortunately this bay is not representative of the remainder of the farm where higher efficiencies would be expected.

Table 2. Summary of results.

Farm	No of Irrigations	Mean Application Efficiency* (%)	Recommended Action
A	6	95	Nil required
B	1	87	Monitor more events
C	5	92	Nil required
D	9	74	Reduce time to cut-off to 100 min
E	5	63	Irrigate less frequently, **reduce flow rate**, cut-off when advance reaches 70% of length
F	6	68	Cut-off at 90 min, irrigate less frequently and at consistent soil moisture
G	7	63	None possible - conduct further trials on a more representative bay
H	2	90	Cut off when advance reaches 50% of length
I	5	56	Grade bay, flow rate 20 ML/d, cut off at 100 min & re-evaluate

It is interesting to note that on average the farmers growing fodder crops performed better than those irrigating permanent pasture. Reasons for this were:

- selection of irrigation durations to minimise runoff,
- greater soil moisture depletion prior to irrigation and hence larger irrigation applications, and
- greater consistency in the use of the soil moisture data in deciding when to irrigate.

There is of course no reason why all irrigators could not follow these same principles.

The stand out performer was farm A where very consistent management was applied, commencing each irrigation at about the same moisture content (soil moisture deficit of 90 mm) and using constant irrigation durations (90 min) that minimised tail-water runoff. Application efficiencies on this farm were consistently high, between 90 and 100%.

Lessons Learned

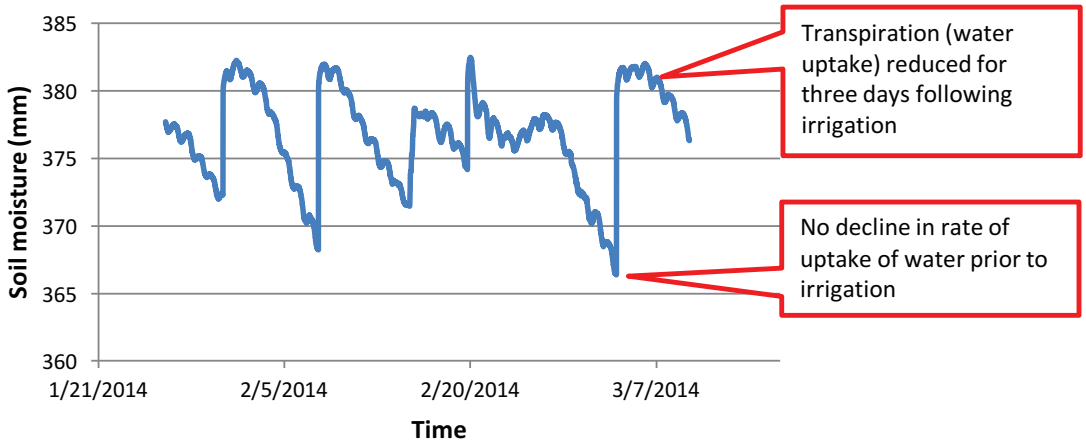
As well as quantifying efficiencies, the observations and circumstantial evidence from the trial suggest the following lessons might apply, namely:

1. Excessively long irrigation durations are the principal cause of low efficiencies.
2. Soil moisture data is crucial for the optimal management of irrigated pasture and should lead to increased irrigation intervals.
3. Pastures are deeper rooted and/or are drawing water from deeper in the soil profile.
4. Waterlogging is a major consequence of inefficient surface irrigation.
5. Less frequent irrigations and shorter durations will reduce the incidence of water logging and should give greater pasture productivity.

Together they suggest the possibility of substantial change to the way bay irrigated pastures are managed.

Pastures certainly appear to be irrigated too frequently. For example in the soil moisture trace of Figure 1, there is no evidence of decline in the rate of uptake of moisture in the day immediately preceding each irrigation, i.e. soil moisture prior to irrigation is still well above the true refill point. Further the figure also shows that the pasture is drawing moisture from below the deepest sensor, suggesting that the effective root zone of the pasture is deeper than most growers presume. This means larger soil moisture deficits and greater irrigation intervals should be possible without the pasture suffering stress or yield decline. This notion is supported by the successful management on farm H that irrigated on a 12 to 15 day irrigation interval during the same period as shown in Figure 1 without any apparent detriment to the pasture yield or species mix.

Figure 1. Soil moisture trace for farm F during Feb 2014.



Irrigation evaluations show irrigators typically applying 30% more water to the field than is required to replenish the soil moisture deficit. The result is excessive tail-water runoff and deep percolation losses (along with significant nutrient loss), extended periods of drainage following irrigation, residual water remaining in the micro-topography of the field, and water-logging of the surface soils. Soil moisture probe data (Figure 1) shows that this can cause the pasture to shut down and cease transpiring for 2-3 days after irrigation with consequent loss of productivity. Two days loss of growth following each of 10 irrigations in a season amounts to a potential loss of production in excess of 20%. These periods of extreme wetness also reduce the time available for grazing.

Incorrect (excessive) irrigation durations are the prime cause of inefficiency (over-irrigation), leading to runoff and/or deep percolation losses. The previous work has shown that correct selection of irrigation duration can maximise application efficiency and eliminate waterlogging. As farmers move to higher flow rates the need for accuracy and precision in the selection and management of irrigation duration becomes even more critical.

A prime example of the importance of irrigation duration is farm F. Six irrigations at this site were available giving an average application efficiency of 68% (range 61 to 78%) with the entire loss being tail-water runoff resulting from excessive irrigation durations. Reducing the irrigation duration to 90 min (from the current 120 min) would reduce the tail-water runoff substantially and raise the application efficiency to about 90%. It would also eliminate the long drainage times and the presence of free water remaining on the surface of the bay following completion of the irrigation and thus contribute to reducing the incidence of waterlogging.

Conclusion

The evidence (observational and circumstantial) suggests a sea-change is required in irrigation management that will lead to more productive, water use efficient, and environmentally friendly bay irrigated pastures. The features are:

- high flow rates to minimize water losses to deep percolation,
- automation to give precise control of irrigation durations,
- real-time selection of irrigation duration to optimize performance thus eliminating run-off losses, and
- consistent management based on soil moisture monitoring.

Together they should:

- mean less frequent and deeper irrigation applications and higher irrigation application efficiencies,
- eliminate residual water on bays and reduce waterlogging,
- increase pasture productivity and create longer windows for grazing, and
- increase opportunities for utilization of incident rainfall.

Acknowledgements

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Managing seasonal variability with soil moisture monitoring devices

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Introduction

Soil moisture probes have now been successfully implemented in dryland cropping systems across the state with a range of state government and community funded projects. Early adopters in the industry have also investing in the technology for greater on-farm benefits. Interest from both service providers and farmers continues to increase with greater understanding of the data and self-interpretation of regional conditions in a time efficient manner that displays actual soil conditions, rather than an estimate.

In 2011, a GRDC national farmer survey, reported an increase in the percentage of the crop where soil moisture is being assessed through the season since the previous survey in 2009. In-crop soil-moisture monitoring has developed in all cropping areas, particularly in Victoria with a growing network of monitoring points across the state.

Materials and Method

Nine soil moisture monitoring sites were commissioned in 2011 across cropping regions of Victoria. These record soil water content at one location from 30cm down to one metre as a reference point for a paddock. Capacitance probes with moisture sensors every 10cm record soil water changes every hour and provide an image of the soil profile. The mobile network is used to send the data to be securely stored on a server that is accessed with the internet. Farmer focus groups were generated based on recognized cropping regions and linked to local sites to assist in the validation of examining deep soil moisture and determining usefulness, usability, and availability. Participants were educated in interpretation of data, received regular email updates explaining recent soil water changes and had access to live data via a soil moisture graphing website.

In 2013 an online survey was sent to the 150 people on the email distribution list who received information about the project and its findings. The distribution list was created from a combination of either farmer involved in the focus groups or have been exposed to an introductory session from the DEDJTR which described the project.

Results

Over the seasons of monitoring the project has built up knowledge of estimated crop upper and lower limits in different soil types across different crops. The seasons were quite extreme with at least one wet summers or wet winters that established crop upper limit. The majority of the growing seasons, have been low decile and have seen a huge depletion of soil moisture reserves through late August to October. The value of sub-soil moisture has been clearly evident and participants have been amazed of the ability of crops to use moisture from 60cm and beyond and how quickly a large biomass crop will use moisture in Spring.

The following are examples of where this information could be used to assist in decision making in dryland cropping.

In low rainfall areas, using soil moisture probes may aid crop choice decision making, guided by pre sowing plant available water and also the time of sowing where good soil moisture reserves gives confidence to sow by the calendar. In higher rainfall areas, soil moisture does not influence crop choice as farmers will follow rotations as guided by Best Management Practices. Knowing the soil moisture levels in high rainfall zones will allow strategic inputs through the growing season to target potential yields.

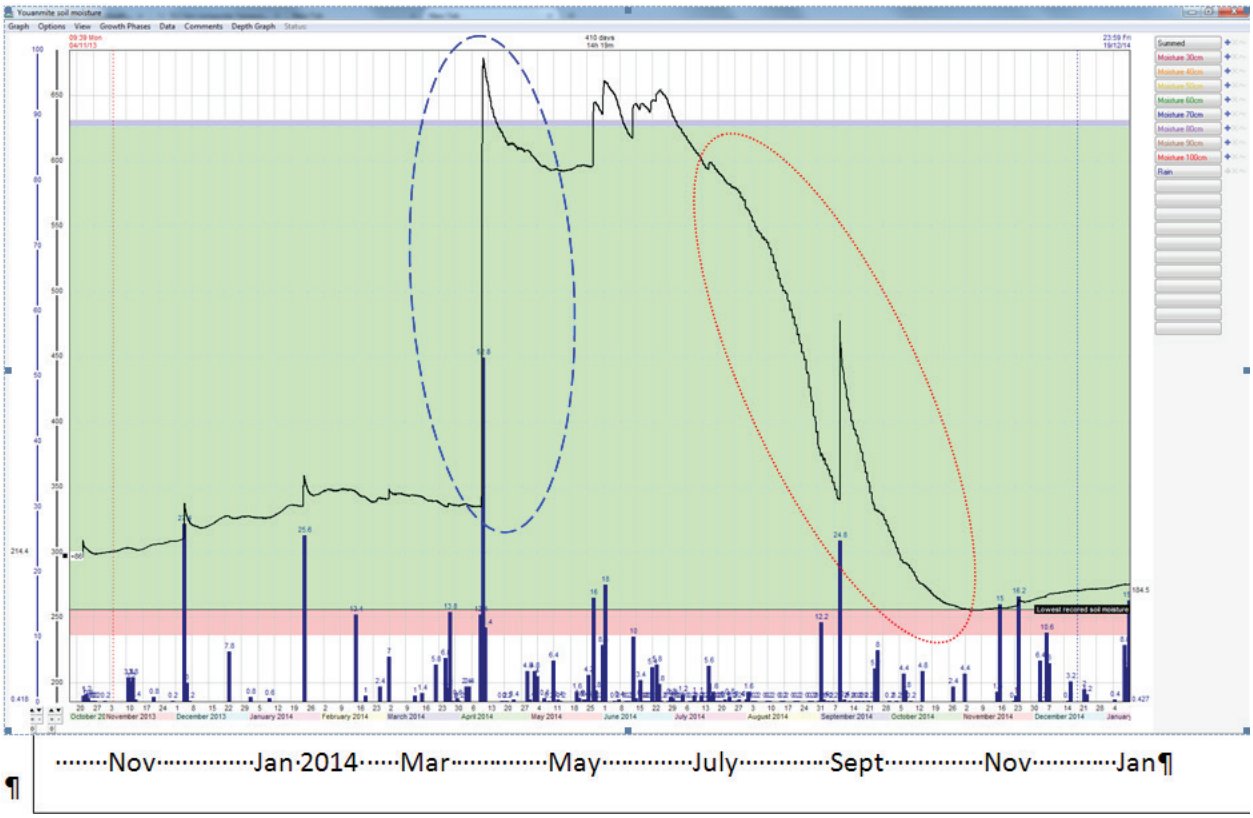

Figure 1. Summed soil moisture graph to display accumulation of soil moisture through Autumn and depletion through Spring at medium/high rainfall zone.

Medium/high rainfall site at Youanmite (North East Victoria). The green shaded area is where plant moisture use has been observed over the monitoring period, and the red shaded area below is nearing crop lower limit and moisture stress. The black line is a summed total of soil water content from all the sensors (30cm down to100cm).

The dashed blue line oval highlights the accumulation of soil moisture in the profile after consistant rains in the months leading up to April 9th-12th rain that charged up the soil profile to readily absorb 83mm. This established ideal deep soil moisture conditions for cropping in North East Victoria in 2014 and inputs such as nitrogen were regularily applied to crops in the region.

The dotted red oval highlights the soil moisture use particularily during August when plant water demands were sourced from stored soil moisture with limited rain being recored (June and August). Half the profile of moisture was used by the crop in this period. The late top dressing of nitrogen that was orginally planned for August was not applied with the knowledge of this rapid water depletion in the profile. Good rains were received mid September at wheat flowering but high yield potentials had been lost by this time.

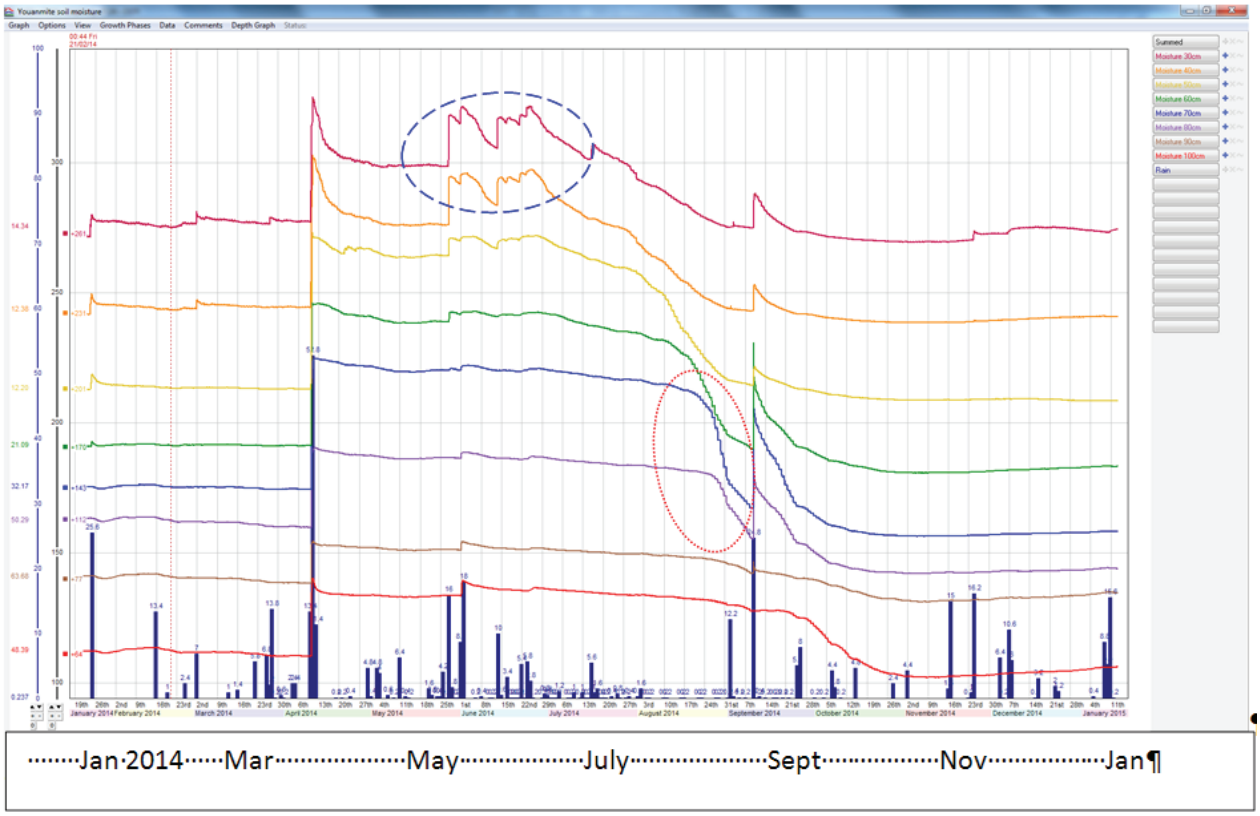

Figure 2. Individual soil moisture sensor graph (Youanmite) 2014 season

The dashed blue oval indicates the time in June 2014 when the profile was saturated and traficability was an issue. By the end of August, the wheat crop was using most moisture from 80cm (red dotted oval). The wheat crop yielded 4.5t/ha and finished grain-fill by using moisture from 100cm in October.

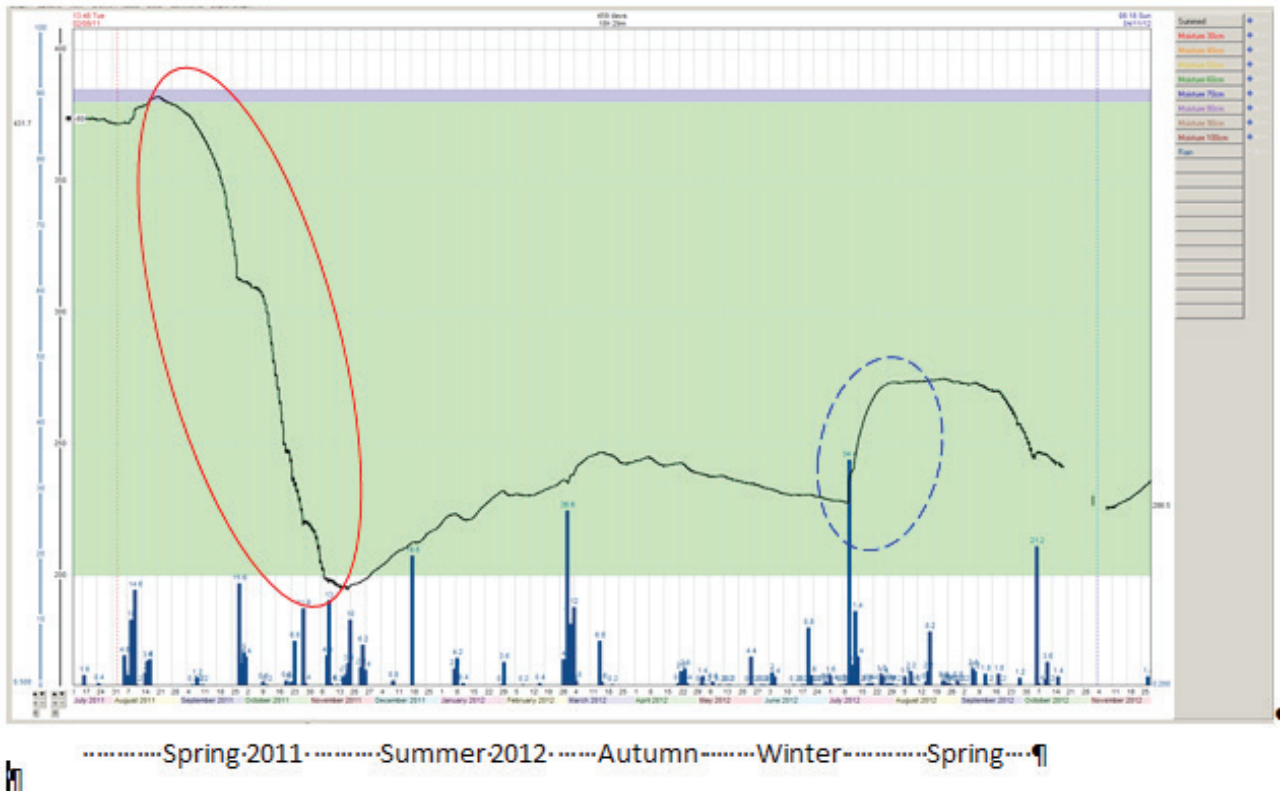

Figure 3. Summed soil moisture graph of the Mallee (low rainfall zone) at Speed – season 2011/12

Figure 3 displays the depletion of deep soil moisture reserves during spring (highlighted by the dotted red oval) after a wet start to the season in the Victorian Mallee in 2011. With knowledge of the soil conditions from the moisture probe, all crop types were an option to be grown in that season. The wheat crop at this site yielded an average of 3t/ha. In the Summer and Autumn of 2012, lack of rain failed to increase soil water reserves and in a low rainfall environment, crop types such as canola were classified as a high risk crop. Canola has a large water demand and unless moisture reserves are in the soil at sowing, chances of cropping profitability are decreased. With a dry profile at sowing, a low risk crop of barley was grown and it was only in mid-winter when there was any increase in soil moisture (highlighted by the dashed blue oval). Crop inputs were managed according to the measured conditions and barley yielded an average 1.8t/ha.

The evaluation of the soil moisture monitoring service with the participants involved found that
-95% of people rated the single source point monitoring system as a rough guide to seasonal conditions with 60% of respondents to the survey thinking the information is relevant to their business.

-The relevant information is being used to confirm decision making during the growing season.
-A high percentage of people exposed to the data, rate their ability to assess soil moisture conditions higher than when the project started four years ago.

33% percent of people in the survey hoped to install their own devices either in a paddock or across their whole farm.

Discussion
Grain growers current cropping systems may not be maximising water use efficiency, if they are using subjective moisture measurements. Limited number of Victorian grain producers are able to monitor water available to the crop and may be making poor management decisions. With a review of the soil moisture monitoring services from DEDJTR, we found that program participants had improved their ability to asses soil moisture conditions and that the one source point measurement would be rough guide to seasonal conditions.

Conclusion
Under a scenario of greater climate variability, this change will increase the importance of input decisions based on a sound estimate of water limited yield potential through modelling or moisture probes. Management decisions determining crop type and inputs such as nutrition are identified where knowledge of deep soil moisture levels may assist with risk management. Understanding the duration of time a full profile of soil moisture will last in normal spring conditions can provide essential information for farmers to make decisions during the growing season.

DEDJTR has developed a system that others may use as a pathway to implement monitoring devices on farm.

Developing a profit-risk decile calculator to capture farm risk

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Abstract
In dryland farming systems, farmers who increase their cropping intensity, tend to increase their downside risk. Consequently, farmers are increasingly exposed to financial and income risk due to additional costs of capital adjustment and increasing levels of enterprise debt. To help farmers analyse farm management decision across the growing season rainfall deciles, a farm-scale profit-risk decile calculator has been developed. A key feature of the profit-risk decile calculator is the ability to compare alternative strategies using a range of financial and economic measures in the same analysis. Site-specific versions of this calculator have been developed using workshop-based consultation between farmers, advisers and researchers for two regions in South Australia. We present a case-study farm developed for Cummins on the Lower Eyre Peninsula, South Australia to demonstrate the capability of the tool. We provide an overview of how the profit-risk decile calculator was developed, including input requirements, outputs generated and an interpretation of results. Using an example of high versus moderate nitrogen (N) management intensity, we demonstrate how farm risk can be explored for a range of outputs; either for a single calendar or rainfall decile year, or after a five-year run of seasons. The aim of this tool is to account for both production risk and business strength such that farmers and their advisors will make better informed decisions despite increased intensity and complexity of farming.

Key words
Profit – risk, decision support, Lower Eyre Peninsula, N management

Introduction
Assessing the merits of a new farming strategy can be challenging. Many farming decisions are based on projected profits in an average year. However, often maximising profit for an average year will not reduce risk, and understanding the trade-offs between profit and risk is complex (Monjardino et al. 2013; 2015). Risk varies with the climate, soil type, farm enterprise mix, commodities and input prices and the level of individual risk-aversion (Harwood et al.1999). A study of the perceptions of risk of Eyre Peninsula farmers ranked climatic variability as the most important source of risk, followed by financial risk and government policy (Nguyen et al. 2007). Farmers can manage risk by reducing variability, transferring risk or building the farm's capacity to deal with risk. Strategies are varied and include enterprise or geographical diversification, maintaining financial reserves and leveraging, leasing land or machinery, increasing liquidity, crop insurance, generating off-farm income, adjusting farm input, or changing farming practices (Harwood et al.1999). However, these strategies cannot be successfully evaluated without a careful analysis of the potential impacts on farm business performance. Therefore, a tool that allows individual farmers to explore these trade-offs is potentially useful. As climate is the key driver of crop production, and farmers perceive this risk to be the greatest. The calculator uses rainfall deciles and resulting yield responses as the primary driver for assessing business risk. The profit-risk decile calculator allows for comparison between current farm operations and alternative management strategies to examine how it may perform over a range of rainfall deciles.

The profit-risk decile calculator was developed with the aim of utilising the outputs of complex bio-economic modelling (Monjardino et al. 2013; 2015) in a format that farmers and advisers could more easily manipulate. The calculator requires farm-based data, and in this case it was generated through an iterative process involving researchers, farmers and consultants in a series of small workshops. This lead to the creation of case-study farm which enabled advisers and farmers to complete comparative scenario analysis, and in this paper we compare different N management strategies at the farm scale.

Methods
The profit-risk decile calculator requires inputs of seasonal crop production including local rainfall deciles (prefilled for the users), crop area according to soil type, enterprise mix, fixed and variable costs, farm ownership, farm assets, as well as crop yield associated with a given soil type, management strategy and rainfall decile (Figure 1). The input data was generated in workshop settings to develop a local case-study farm

which can then be tailored by the individual post-workshop. Rainfall deciles were calculated using 56 years of daily weather data, with rainfall the sum of growing season rainfall (April to October) plus 25% of the fallow rainfall (as is the case for water use efficiency calculations). The years within a given rainfall decile are listed together in the calculator as analogue years. The profit-risk decile calculator outputs are grouped by whole-farm economics and finance measures. Economic measures include profit and loss, earnings before interest and tax (EBIT), and farm net profit before tax (FNP). Farm finance measures include net worth, equity, return on capital and cash flow. The results can be viewed either for a single calendar, rainfall decile year, or after five-year run of seasons which are a historical sequence or user selected sequence of seasons.

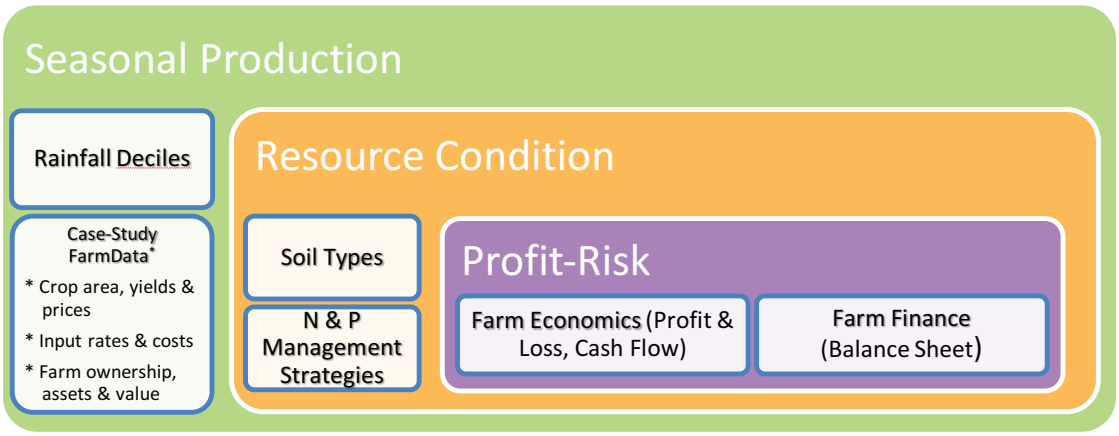

Figure 1 data requirements and outputs for the 'cash flow calculator'

This paper uses a Cummins case-study farm to illustrate features of the profit-risk decile calculator. Two profit-risk workshops were held at Cummins with local farmers, consultants and researchers to establish case-study farms that reflect the local conditions. Cummins is located on the Lower Eyre Peninsula (-34.26, 135.73) with average annual rainfall of 400 mm. The key attributes of the case-study were:

- 1400 ha farm valued at $7,000/ha
- Manager allowance of $50,000 and staff wages of $51,500/year
- An overdraft of -$2,000,000
- Plant and machinery inventory value of $1,120,000
- Total fixed costs of $96,750/year
- Two soil types, clay (75% of cropped area) and waterlogging clay (25% of cropped area)

The case-study farm at Cummins was used to compare two levels of N management intensity: a high intensity scenario where 700 ha wheat and 700 ha canola were cropped with applications of 100-300 kg urea/ha and a moderate intensity scenario which has 700 ha wheat, 350 ha canola and 350 ha beans with 100-300 kg urea/ha applied to the wheat and canola only.

Table 1. Yield (t/ha) in response to N management and season type for Cummins case-study farm. Yields were developed using farm records, local trial data and APSIM outputs.

	High N Management Intensity					*Moderate N Management Intensity*				
	Decile 1	Decile 3	Decile 5	Decile 7	Decile 9	Decile 1	Decile 3	Decile 5	Decile 7	Decile 9
	Wheat Yields (50% of farm area)					*Wheat Yields (50% of farm area)*				
Clay	2.4	2.9	3.4	4.5	5	2.7	3.2	3.8	5	5.5
Waterlogging Clay	2.4	2.9	3.4	4.5	4.1	2.7	3.2	3.8	5	4.5
Fertiliser Input (kg Urea)	100	140	180	250	275	100	140	180	250	250-300
	Canola Yields (50% of farm area)					*Canola Yields (25% of farm area)*				
Clay	0.9	1.3	1.6	2	2.2	1	1.4	1.8	2.2	2.4
Waterlogging Clay	0.9	1.3	1.6	1.6	1.6	1	1.4	1.8	1.8	1.8
Fertiliser Input (kg Urea)	140	180	240	275	300	140	180	240	275	300
						Bean Yields (25% of farm area)				
Clay						1.4	1.8	2.5	3.0	3.0
Waterlogging Clay						1.4	1.8	2.5	3.0	1.8

Yields varied according to N management, soil type and season (Table 1). The yields used in the Cummins case-study farm were based on a consensus of local trial data (in this case N management trials), APSIM modelled response to N management and historical farm data. Yields have been adjusted for the management scenario, such that the high N intensity has approximately 10% less yield despite equivalent N input (an outcome which appears sensible based on yield measurements available and estimates of the potential benefit derived from having a legume in the sequence).

Results and Discussion

The profit-risk decile calculator outputs economic measures indicating the financial performance of whole-farm business. Generally a higher EBIT indicates better business performance, the calculator compares how EBIT behaves in a average year versus low or high rainfall years, thus adding value to reviewing the farm business performance. The moderate intensity scenario is earning $124 K more than the high intensity scenario in a decile 5, increasing to $148 K in a decile-7 (Table 2). FNP follows a similar pattern, increased from decile 1 through to decile-7, but there was only a small increase from decile 7 to decile 9 due to the effect of waterlogging on yield (Table 2). The difference in FNP between management scenarios was greatest in a decile-7 year, with the moderate intensity scenario generating $151 K more FNP than the high intensity scenario. Cash flow is a measure of liquidity, a positive cash flow indicates that financial obligations are met, this is especially important in low rainfall/yield years (decile 1-3). Both management scenarios started with a -$2000 K overdraft. After one year the cash flow was negative with a decile-1 year; however all other rainfall seasons (decile-3 to 9) showed improved closing balances with the moderate intensity scenario $78-110 K ahead (Table 2). Net worth and equity both reflect how the farm business is performing after a single year. In both scenarios equity was greater than 80% and net worth had growth in decile 3 through to decile 9 (Table 2). Again the moderate intensity scenario performed better across all deciles.

Table 2. Profit-risk decile calculator outputs comparing the high and moderate N management intensity scenarios on the Cummins case-study farm after one year.

Decile	Start	Decile 1	Decile 3	Decile 5	Decile 7	Decile 9
High N Intensity						
[a]Earnings Before Interest, Leasing and Tax (EBIT)		$95k	$258k	$413k	$645k	$705k
[b]Farm Net Profit Before Tax (FNP)		-$211k	-$46k	$111k	$346k	$408k
[c]Cash Flow (Expected balance at bank)	-$2,000k	-$2,104k	-$1,939k	-$1,782k	-$1,547k	-$1,485k
[d]Net Worth	$8,920k	$8,709k	$8,874k	$9,031k	$9,266k	$9,328k
[e]Equity		81%	82%	84%	86%	86%
Moderate N Intensity						
Earnings Before Interest, Leasing and Tax (EBIT)		$175k	$334k	$537k	$792k	$812k
Farm Net Profit Before Tax (FNP)		-$129k	$32k	$238k	$497k	$517k
Cash Flow (Expected balance at bank)	-$2,000k	-$2,022k	-$1,861k	-$1,655k	-$1,396k	-$1,376k
Net Worth	$8,920k	$8,791k	$8,952k	$9,158k	$9,417k	$9,437k
Equity		81%	83%	85%	87%	87%

[a]EBIT = sum of gross margins - overheads, [b]FNP = EBIT – depreciation - interest, [c]Cash Flow = FNP - principal repayments -allowance for machinery or cash purchase, [d]Net Worth = total assets - total liabilities, [e]Equity = net worth/ total assets.

Measuring farm performance over a range of season types is beneficial, as it shows the resilience of the farm over time and the ability to recover from a financial shock. This is valuable for developing the 'big picture' in scenario analysis and shows how discounted cash flow, equity and net worth are expected to perform over time. In the case study, a run of historical years starting in 2002 and finishing in 2006 corresponding to decile 2, 7, 4, 8 and 1 was analysed. The moderate N input system consistently performed better regardless of season type, with small differences in the first couple years and the potential impact of the differences after five years more substantial (Figure 2), with $409 K better cash flow in the moderate intensity scenario.

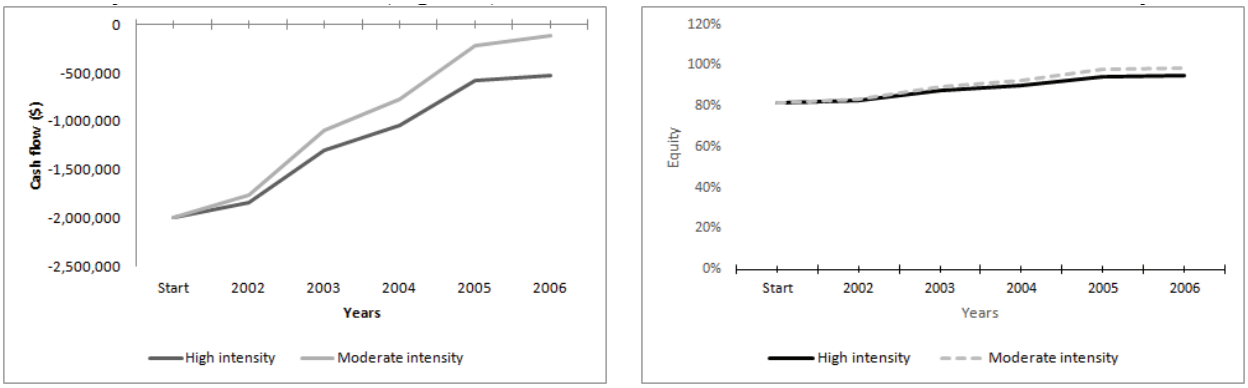

Figure 2 Graphical representation of the 5 year outputs discounted cash flow on the left and equity on the right. The black line shows the high intensity scenario and the grey line shows the moderate intensity scenario.

Conclusions

This paper demonstrated some features of the profit risk calculator by using a Cummins case-study farm. The tool was employed to compare N management scenarios impact on financial and economic measures in all rainfall deciles, allowing both downside and upside seasonal risk to be explored. We have established that the decile calculator is locally relevant, simple to use and practical tool that can help users to better understand how seasonal risk impacts on their farm business and their farming decisions. The tool has the flexibility to explore a range of farming scenarios with consideration given to maximising profit and minimising risk according to user preference.

Acknowledgments

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Improved testing of soil water balance models; an example using APSIM

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Abstract
Soil water balance models provide input to models of agricultural and natural systems that inform soil and crop management. Independent empirical testing is needed to establish their reliability and accuracy.

We consider and contrast statistical methods used to test models, and highlight some common errors. Our metric of model accuracy is the skill (R^2) in predicting the gain in soil water (mm) from the start to the end of summer fallows. APSIM is benchmarked against Fallow Efficiency (FE), which requires only a single parameter. APSIM was supplied with detailed definitions of the starting conditions, the soil, tillage and meteorological conditions.

FE was poor at predicting fallow gain in soil water. APSIM was much better, simulating the fallow gain in soil water for two tillage treatments at Greenmount (residues burnt and zero till) with R^2 of 0.5 and 0.65 with respect to the observed=predicted line. As expected the lines of best fit (predicted = $a + b$.observed) had higher R^2. For a mean observed gain in soil water of 108 mm the mean absolute errors across the two treatments were 26 and 47 mm for APSIM and FE respectively. APSIM had no skill (R^2<0) in predicting the amount of extra soil water (mm) stored by the zero till treatment.

Key words
Simulation modelling, statistical testing, fallow, tillage

Introduction
Soil water models combine mathematical functions that represent infiltration and runoff, potential and actual soil evaporation and transpiration, soil water extraction and redistribution, deep drainage and other processes. With several co-dependent processes being simulated, and sub models that are usually developed independently, it would be a mistake to assume that these models are accurate. With many parameter choices affecting the results, it is also a mistake to assume that a user, even a highly skilled user, can obtain accurate and reliable results. There was no adjusting, "tuning" or "calibrating" of any parameters to fit observations.

These models are important. APSIM (Keating *et al*. 2003), PERFECT (Littleboy *et al*. 1989) and HowLeaky (McClymont *et al*. 2015) have been used to simulate crop yields (e.g. Whitbread and Hancock 2008), runoff and erosion (e.g. Thornton *et al*. 2007) and deep drainage (e.g. Robinson *et al*. 2007) respectively. Their soil water balances have all been developed from earlier models such as CREAMS (Knisel 1980). Testing the accuracy of the eminent agronomic model APSIM is therefore an appropriate case to investigate.

How can accuracy be assessed? Scatterplots of observations and model predictions are popular, combined with an r^2 or root mean square error (RMSE). For example, Whitbread and Hancock (2008) found that "A regression of the predicted against observed yields result in an r^2 = 0.66 and RMSE of 0.64 t/ha, n = 35 (Fig. 2a)". However, soil water presents a special statistical problem. Simulation conditions including soil water are usually set equal to the observations at the start of the simulation, creating an artificial r^2 of 1 at that time. The r^2 declines over time during the simulation period as the artefact of initialisation is diluted. Short simulations such as fallows, with widely varying starting conditions are especially affected by this effect. Unfortunately, these were the conditions under which the soil water balance (SoilWat) in APSIM (Probert *et al*. 1996) was "validated". In this study we improve model testing by plotting *changes* in observed and predicted soil water, eliminating the artefact of initialisation and subsequent auto-correlation.

Methods

The two statistical approaches (r^2 for the line of best fit and R^2 for the 1:1 line) are applied to a case study from the Greenmount erosion and farming systems experiment. Fallows are simulated to avoid testing the complexities of estimating transpiration and soil water extraction by roots.

(a) Statistical methods

A scatterplot of observed data (x) against predicted or simulated data (y) is a common demonstration of model fit. Perfect correspondence between the two datasets results in the data (x_i,y_i) falling on a line where y = x with a coefficient of determination (r^2) of 1. An r^2 or R^2 value is commonly quoted for the line of best fit between x and y, according to y = a + b.x. However the desired relationship is y = x. This is an important difference, as we shall demonstrate.

Although sometimes confused, the statistic r^2 is only used for the line of best fit (y = a + b.x), where it is equal to the correlation coefficient r squared, while R^2 is a generic indicator of goodness of fit that can be applied to any relationship, including our y = x. For all relationships other than the line of best fit r^2 will be greater than R^2. We calculate both the r^2 and R^2 for y = x. We also calculate the mean absolute error (mean|observed-predicted|), which is probably a little easier to interpret than the RMSE.

We have used the standard method of calculating R^2, shown in Equation 1. The parameters are the predicted data y_i, with a mean of $\bar{y}$, and the corresponding data for the fitted function f_i.

$$R^2 = 1 - SSerror / SStotal \qquad \ldots(1)$$

where $SSerror = \sum i(fi - yi)^2$

and $SStotal = \sum i(yi - \bar{y})^2$

(b) Greenmount fallows

Each of the soil water measurements is the mean of 9 gravimetric samples (5 cm cores) distributed spatially through a treatment in 3 groups of 3 (end, middle, end). The bulk density was measured in each soil layer. The volumetric water contents were downloaded from http://www.howleaky.net/ for 2 types of fallows at Greenmount (Burnt and Zero Till), summarised in Table 1. Fallow length as shown in Table 1 is the number of days between the first post-harvest soil water measurement and the last pre-plant measurement.

Table 1. Characteristics of summer fallows at the Greenmount site (data from http://www.howleaky.net/index.php/library/supersites/97-library/site-summaries/cropping/greenmount/146-greenmount-level-4).

	Burnt treatment		Zero till treatment	
	mean	(range)	mean	(range)
Fallow length (days)	151	(76 - 242)	126	(78 – 199)
Fallow rainfall (mm)	268	(63 - 468)	304	(95 – 305)
Soil water gain (mm)	114	(10 - 210)	103	(36 – 248)

(c) Simulation methods

APSIM accounts for 75% of publications concerning crop simulation in Australia (Robertson and Carberry 2010) and was therefore chosen to represent the cohort of Australian soil water balance models. Version 7.7 (build 11 Dec 2014) was used via the standard user interface. Each fallow was simulated separately, with the simulated soil water being reset to the observed amount on the date of first measurement after the harvest of the wheat crop and observed and predicted gains were calculated from that time. The burning of crop residues was simulated in APSIM using the relevant date and tillage option.

The FE method equates fallow soil water gain to 25% of fallow rainfall. Efficiencies of 20% and 30% were also calculated. The changes in r^2 and R^2 values were small because the predictions change in unison.

(d) A note of caution

The models are being tested by comparison with observations that are not free from error. David Freebairn (pers. comm.) found a standard deviation of 60mm of measured soil water at a small site with apparently uniform clay soil. There are also uncertainties that change through time; the longer that a site is monitored, the wider the likely spread between the observed upper and lower limits, affecting the simulation model parameters. How long should a paddock be monitored to estimate the limits of soil water? A more complete analysis should be made elsewhere. Suffice to say that investigating the veracity of both the observations and predictions is important.

Results

Figures 1 and 2 show the observed and predicted results from the two treatments at Greenmount. Relative to APSIM, the fallow efficiency method is a poor predictor of the gain in soil water.

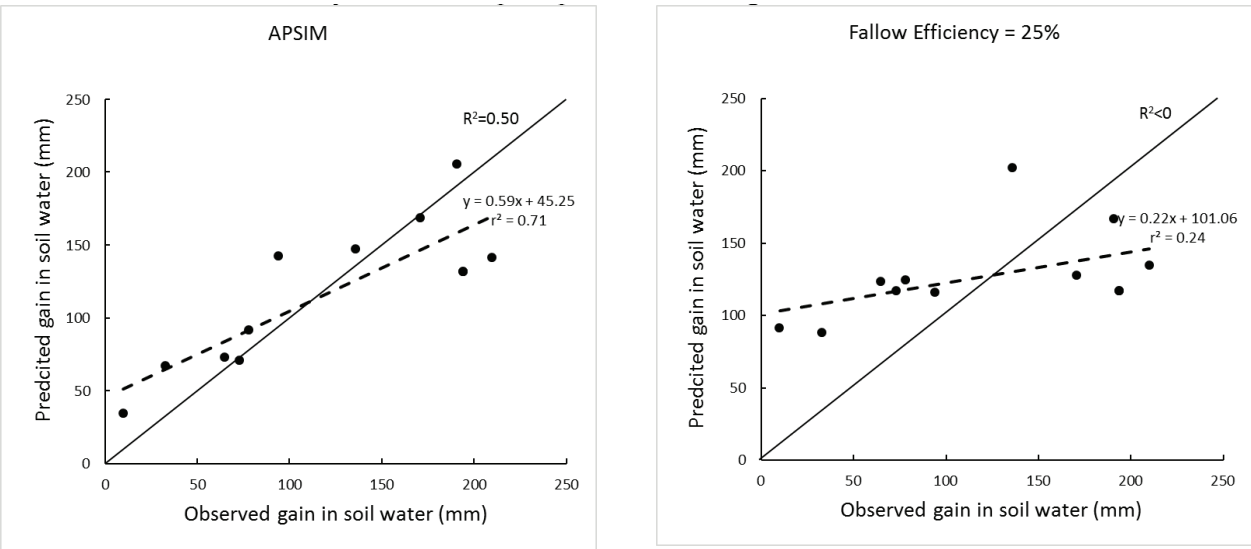

Figure 1. The observed and predicted data for the Burnt treatment.

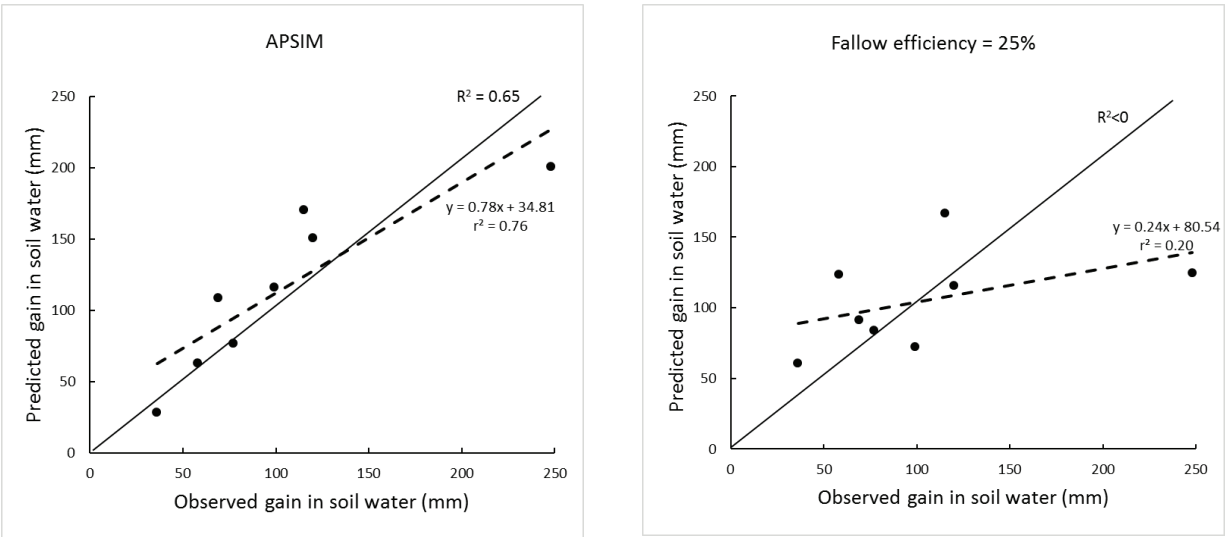

Figure 2. The observed and predicted data for the Zero Till treatment.

Figure 3 shows the observed differences and APSIM's predicted differences between Zero Till and Burnt. The slope of the line of best fit (0.47) is much less than the ideal slope (1.0).

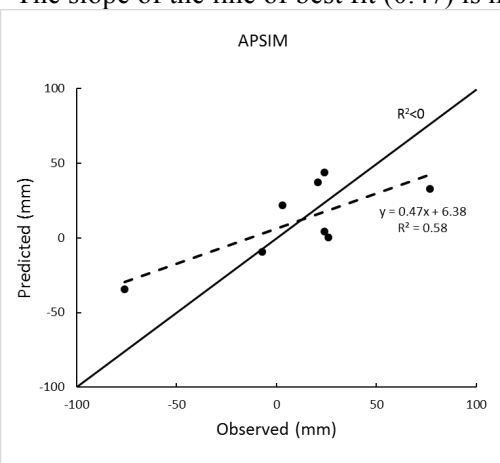

Figure 3. The observed and predicted difference between the Zero Till and Burnt treatments.

Discussion

We have established that the correct metric for judging models is the predicted change in soil water. The correlation between starting and finishing soil water excludes the use of soil water *per* se as a metric.
The lines of best fit for APSIM have slopes well below the desired slope of 1 (0.59 and 0.78, Figures 1 and 2). Consequently, there was a considerable difference in the r^2 or R^2 values for the lines of best fit (0.71 and 0.76 for the two treatments) and the observed=predicted line (0.5 and 0.65). The lines of best fit for the FE model have low slopes (0.22 and 0.24, Figures 1 and 2). The $R^2<0$ for the observed=predicted lines indicate that the mean observation () explains more of the variation in the observed values than the FE predictions.

The artificially high r^2 values for the lines of best fit overestimate the accuracy of both models; APSIM by a moderate amount (R^2 inflated by 21% and 11%) and FE by a large amount (R^2 inflated by 22 and 24%).

For a mean observed gain in soil water of 108 mm in these fallows, the mean errors (absolute) for the two treatments were 26 mm for APSIM and 47 mm for FE. The largest errors (absolute) were 69 mm for APSIM and 127 mm for FE. APSIM had no skill ($R^2<0$) in predicting the amount of extra soil water (mm) stored by the zero till treatment relative to the burnt treatment. Are APSIM users aware of this lack of skill?

The APSIM model is clearly better in this case than the FE model. This is not too surprising given that evaporation and runoff vary between fallows in ways that FE may not represent. The single, lumped parameter of the FE model appears insufficient to represent the diverse physical processes of soil water storage, while the dozens of parameters of APSIM and similar models can better represent these processes. Further research is required to establish which parts and parameters of APSIM-like models are critical to the task of predicting soil water storage and which, if any, are unnecessary or unnecessarily complicated.

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IrriSAT – weather based scheduling and benchmarking technology

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Abstract
IrriSAT is a weather based irrigation management and benchmarking technology that uses remote sensing to provide site specific crop water management information across large spatial scales.

Developed in partnership with the CRC for Irrigation Futures, IrriSAT uses satellite imagery to estimate crop coefficients (Kc) at a 30 m resolution. IrriSAT calculates Kc from a linear relationship with satellite derived Normalised Difference Vegetation Index (NDVI). Daily crop water use is determined by simply multiplying Kc and daily reference evapotranspiration (ETo) observations from a nearby weather station. A seven day forecast of ETo is also produced.

A delivery platform is being developed using the Google App Engine. The app will provide easy access to the IrriSAT crop water use data, which coupled with weather and crop water use (ETc) forecasts will enable irrigators to track their soil moisture deficit and better manage irrigation schedules. Spatial crop water use information determined by IrriSAT is also available through the IrriSat app and will allow users to investigate water use difference within and between fields. This information can be used for changing management decisions along with investigating the impacts of these decisions.

Introduction
Irrigation water is scarce, there are competing needs between the environment, urban communities and agricultural uses (Roth et al. 2013). In the Gwydir Valley in Northern NSW, on average irrigators only receive about 30 per cent of their water entitlement (NSW Office of Water 2015). Therefore, maximising on-farm water use efficiency is vital to farm profitability.

Irrigation scheduling matches the timing and volume of irrigation water supplied for crop needs (Wigginton et al. 2012). Of Australian cotton growers, 70 per cent use soil moisture monitoring to assist their irrigation decisions (Roth 2014). This technique often relies on one soil water content profile to represent very variable fields.

Weather based irrigation scheduling estimates crop water use (ETc) as the proportion of reference evapotranspiration (ETo), calculated from climate parameters using a multiplier or crop coefficient (Kc), which varies with the stage of crop growth (Allen et al. 1998), where ETc = ETo x Kc. The weakness in this approach is in estimating the crop coefficient (Trout and Johnson 2007) and often generic Kc curves do not match the actual crop water use. Weather based scheduling techniques have not been widely adopted in the cotton industry due to the problem of determining site specific crop coefficients. Kc is related to crop light interception and canopy cover which can be estimated from remotely sensed observations of the normalised difference vegetation index (NDVI) (Trout and Johnson 2007).

IrriSAT is a weather based irrigation service driven by satellite data to estimate Kc and ETc at the same 30m resolution as the satellite (Hornbuckle et al. 2009). IrriSAT was successfully used in the Murrumbidgee Irrigation Area by grape and citrus irrigators to estimate daily crop water use and provide irrigation scheduling information to growers (Hornbuckle et al. 2009). It was first trialled in the cotton industry by two consultants in the Gwydir Valley in Northern NSW during 2009/10. In 2010/11 it was trialled by ten cotton consultants in Northern NSW over 20,000 ha. In 2011/12 the IrriSAT technology was applied over 75,000 ha. Although developed primarily as an irrigation scheduling tool, IrriSAT data also provide a means of benchmarking crop water productivity at field, farm and regional scales.

The Australian Cotton Research and Development Corporation (CRDC) is funding research by NSW DPI, Deakin University and CSIRO to roll out IrriSAT across the cotton industry as an irrigation scheduling tool and to use the data to benchmark crop productivity for all Australia's cotton growing regions.

IrriSAT

IrriSat integrates two sources of information, satellite imagery (to calculate NDVI) and reference evapotranspiration (ETo from on-ground weather stations) to estimate the crop coefficient (Kc). The crop coefficient is used to adjust the ETo for a specific crop type, where crop height, albedo, canopy resistance and bare soil evaporation is integrated into a single parameter specific to that crop type.

Satellite data and calculations

Normalised Difference Vegetation Index (NDVI) is calculated as the ratio of the difference to the sum of the near infrared reflectance (R_{NIR}) and red reflectance (R_{Red}) and range between 0-1 such that:

$$NDVI = \frac{(R_{NIR} - R_{Red})}{(R_{NIR} + R_{Red})} \qquad \text{Equation 1 (Tucker 1979)}$$

Remote sensing of the crop is undertaken using the Landsat satellite platform. These satellite platforms have been used because they are free and have the spectral, spatial (30m pixels) and temporal (8-16 days) resolutions appropriate for IrriSAT. The best available, cloud free data from the Landsat 7 and 8 satellites is selected. While there are small differences between Landsat 7 and 8 (Dandan and Xulin 2014) the NDVI calculated from both satellites is essentially the same.

Trout and Johnson (2007) found a strong linear relationship between NDVI and crop canopy cover for various crops in semi arid areas of California. Since transpiration is proportional to crop cover it is reasonable to relate the NDVI to a crop coefficient value. This approach allows NDVI values to be converted to a crop coefficient and hence produce a Kc map across the satellite image.

The crop coefficient is calculated from the NDVI by equation 2 which is derived from Trout and Johnson (2007).

$$Kc = 1.37 * NDVI - 0.086 \qquad \text{Equation 2}$$

On ground climate measurements

Reference crop evapotranspiration (ETo) is calculated from observations from a network of automatic weather stations installed across most cotton regions. This data is freely available via the IrriGateway website http://www.irrigateway.net/weatherstations. ETo calculations are based on the ASCE Standard reference evapotranspiration equation as detailed in Allen et al. (2005). CSIRO also provides a seven day ETo forecast. The weather station closest to the field or point of interest is used in these calculations.

Daily crop water use

By combining reference evapotranspiration (ETo) and the Landsat derived crop coefficient (Kc), crop water use (ETc) can be determined on a 30m x 30m basis such that:

$$ET_c = ET_0 \times K_c \qquad \text{Equation 3}$$

Using the forecast ETo data, an estimated crop water use for the next seven days can be calculated. Importantly, daily ETc can be summed to calculate seasonal crop water use. This information can be used for crop productivity benchmarking and also for water budgeting.

IrriSAT app

An app is being developed to deliver ETc and Kc to any web enabled platform including smart phones, tablets and desktops. A beta version of the app is currently available at https://irrisat-cloud.appspot.com/, developed using Google App Engine (GAE). Fields are added as polygons drawn by users who must also input the timing and quantity of irrigation and rainfall to drive a daily water balance model. The IrriSat app will have similar functionality to the US Smartirrigation Cotton app http://smartirrigationapps.org

(Vleeshouwer et al. 2015). Currently the IrriSAT app displays NDVI and Kc as surfaces (Figure 1). Time series of field averages of these data can be calculated and downloaded for further analysis. These data will allow irrigators to make better informed water management decisions.

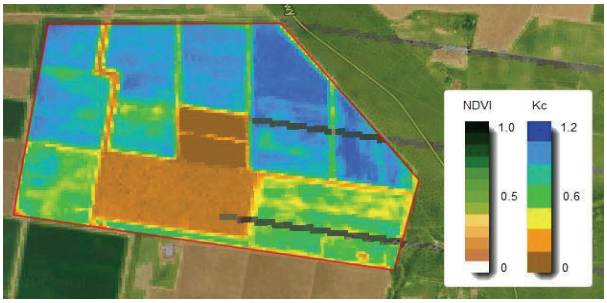

Figure 1: A screen dump of crop coefficients calculated by the IrriSAT Google App

The IrriSAT app will deliver irrigation water management information to irrigators to assist in irrigation scheduling and crop productivity benchmarking.

Benchmarking crop productivity

IrriSAT was used to benchmark around 80 cotton fields in the Gwydir Valley during 2010/11 (Soppe et al. 2012). This initial benchmarking exercise showed that yield increased with water use and that certain practices grouped together (Figure 2). The water use efficiency of the fields studied is indicated by the slope of this plot. However, the deviations from this general trend identify over- and under- performing fields and this holds the key to improving water productivity. For example, a yield of eight bales per ha can be achieved by using between 500 and 650 mm of water. On the other hand, using 600 mm of water can deliver between 7 and 10 bales per hectare of lint. By examining field characteristics and management, the reasons for differences in water use efficiency can be determined.

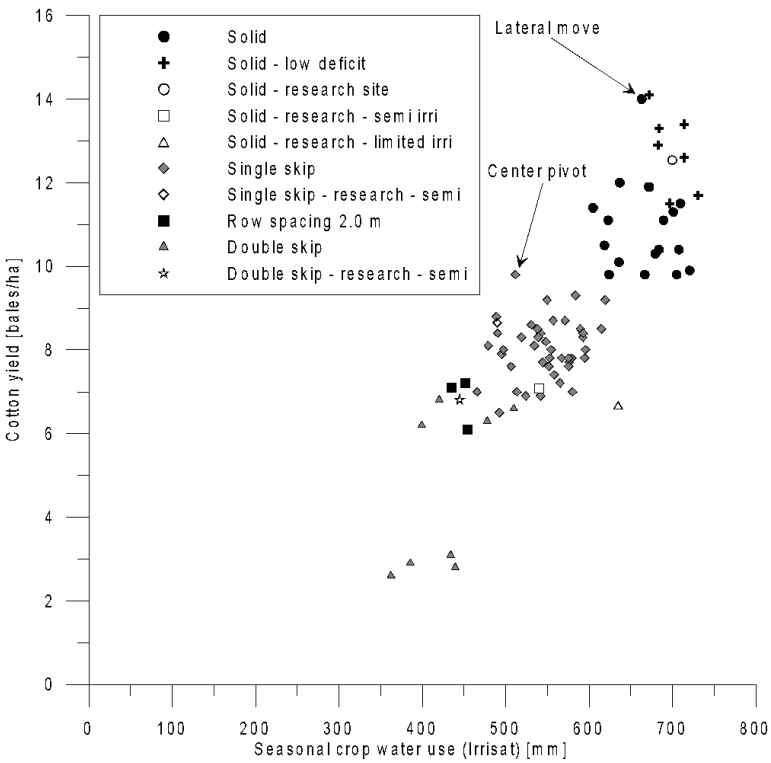

Figure 2: Cotton yield and seasonal crop water use for different row configurations, irrigation systems and water regimes in the Gwydir Valley, NSW for 2010-11 season.

Conclusions

IrriSAT will complement existing irrigation scheduling tools with the advantage of low cost and complete spatial coverage. Preliminary trials of the IrriSAT technology as a benchmarking tool have enabled irrigators to examine variation in crop productivity between fields and farms. Identifying over-and under-performing fields holds the key to improving water productivity.

Key words

Cotton, crop coefficient, irrigation water use efficiency

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