A paradigm shift in farming systems experimentation: deploying a rule-based approach

Lindsay W Bell[1], Kaara Klepper[2], Jayne Gentry[2], David Lawrence[2], Andrew Verrell[3] and Guy McMullen[3]

[1] CSIRO Agriculture and Food, PO Box 102, Toowoomba, Qld 4350, Lindsay.Bell@csiro.au
[2] Department of Agriculture and Forestry, Toowoomba, Qld 4350
[3] New South Wales Department of Primary Industries, Tamworth, NSW 2340

Abstract

In farming systems research, the interactions between various elements of the farming system need to be appreciated. Historically, most farming systems experiments have examined either singular modifications, an approach that can miss important interactions, or they have deployed predetermined changes (e.g. crop rotations) which are too inflexible to represent the dynamic nature of the farming system. To address the complex nature of the farming system in subtropical Australia, a set of strategies was developed as system treatments which were hypothesised to address current and emerging issues in the farming system. A novel aspect of our approach is that each system strategy has a different set of management rules and practices that influence either cropping intensity, crop diversity, nutrient supply strategy and/or management of long-term soil quality. Thus the crop sequences and management practices which differentiate these systems will emerge over time, rather than be specified at the outset of the experiment. Using such 'rule-based' approaches in farming systems experiments reflects how farmers make decisions and offers capacity to test how modifications to these influence systems outcomes much like a real world environment.

Keywords

Nematodes, carbon, AMF, aggregates, structure, grass.

Introduction

Leading farmers in Australia's northern grains region are performing well in terms of achieving the yield potential of individual crops but the performance of the overall system is less well considered. Recent analysis suggests that 29% of crop sequences are achieving 80% of their potential water use efficiency despite adequate nitrogen fertiliser inputs to achieve this (Hochman et al. 2014). The key factors were not related to in-crop agronomy but to the impact of crop rotations, impacts that are not yet quantified but are thought to relate to issues occurring across the crop sequence such as poor weed management, disease and pest losses and sub-optimal fallow management and cropping frequency. Similarly, farming systems are threatened by the emerging challenges of increasing herbicide resistance, declining soil fertility and increasing soil-borne pathogens, which will all require responses to maintain total system productivity. Questions are emerging about how systems should evolve to integrate practices that: maximise capture and utilisation of rainfall particularly when using high-value low-residue crops; reduce costs of production and the likelihood of climate-induced risk; respond to declining chemical, physical and biological fertility; improve crop nutrition and synchrony of nutrient supply; suppress or manage crop pathogen populations; reduce weed populations and slow the onset and prevalence of herbicide resistance. Because of the multi-faceted nature of these challenges, an important need is for a farming systems research approach that develops an understanding of how various practices or interventions come together, quantifies synergies or trade-offs and shows how these interventions impact on whole-of-system productivity, risk, economic performance and sustainability of farming systems. This paper sets out to describe an approach being used in the current farming systems experiments being undertaken in subtropical Australia.

Rethinking design of systems experiments

There is a rich history of farming systems studies across Australia, studies that have provided critical information on the benefits and challenges of changing farming practices. These studies have dealt with a range of issues including long-term fertilisation strategies, no-till or conservation tillage, and crop or crop-pasture rotations. However, as we were developing the concepts and design for a new round of farming system experimentation, some limitations of past approaches were evident. One limitation is the static nature of crop rotations or treatments that are employed over time. For example, crop sequences were scheduled inflexibly rather than emerging dynamically from the strategies that were being tested. This flexibility is particularly important in northern farming system where opportunity cropping systems predominate. Farmers utilise fallow periods to build soil water and their decisions to plant summer and winter crops are triggered by soil water conditions rather than by scheduled crop sequences. Thus a more agile approach to determine the sequence of crops to sow is required. Secondly, many systems experiments have only examined the impact of a single change to the farming system rather than the interactions of several changes. Kirkegaard and Hunt (2010) demonstrated how combinations of stubble retention, fallow management, crop genotype and crop sequence used in the farming system brought about much larger additive gains in potential system productivity and water use efficiency than when each treatment was applied singularly. Thus the research approach needed to explore the synergies or antagonisms between different practices in the farming system.

Our research approach

Northern cropping systems are complex, with a broad range of potential crops with a range of sowing windows in summer and winter, different soil water requirements for these crops, and the capacity to store soil water during fallows for subsequent crops. Hence farmers have a complex set of decisions that drive the farming system with a diverse range of management approaches being used depending on soil and climatic environment. Consultations with leading growers, advisors and other researchers identified four common ‘levers’ that concerned farmers in terms of maximising the performance of the farming system. These were 1) crop intensity or frequency (i.e. the proportion of time where crops were growing), 2) crop diversity (i.e. the range of crops grown/used in the system), 3) nutrient supply strategy (i.e. the provision and source of nutrients, particularly N) and 4) the capacity to maintain long-term soil quality through only grain crops or through the use of pasture leys or cover crops (see Table 1). Hence, a set of system strategies were designed around these issues to address key current and emerging constraints or limitations for farming systems in the northern grains region. These included a ‘baseline’ representation upon which changes in the system strategy were applied either alone or in combination. It is anticipated that this factorial approach will quantify the singular and additive impacts on the various performance metrics of the farming system (see Figure 1).

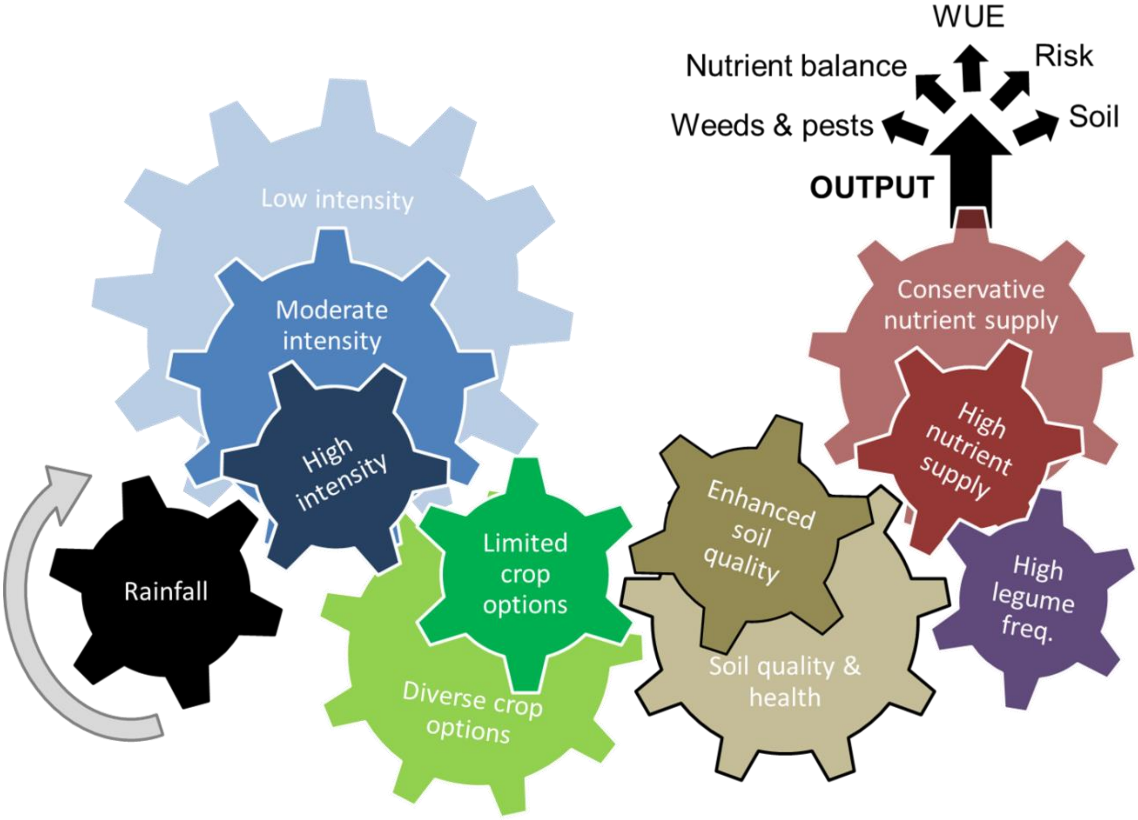

Figure 1. Schematic demonstrating the interrelationships amongst the different crop strategies being employed to examine how these impact on the performance of the farming system.

Table 1. List of key system driver (1-4 below), the range of system strategies being tested and the rules underpinning each of these strategies, along with the rationale and anticipated impacts through deviating from the 'baseline' system rules (indicated in italics) for each of these strategies.

System drivers	Strategy	Rules underpinning system strategy	Anticipated impacts
1. CROP INTENSITY/FREQUENCY			
Moderate crop intensity ^	*Sowing on a conservative PAW threshold*	*Higher PAW requirement to trigger a crop sowing event* (e.g. 60% of PAW of full profile)	
High crop intensity ^	Increase the frequency of crops sown in order to maximise proportion of rainfall transpired by crops	Lower PAW requirement to trigger a crop sowing event (e.g. 30% of PAW of full profile) Sow crops as soon as sowing window opens if PAW trigger met	- Reduced fallow herbicide use - Increased C inputs & soil OC - Increased soil biological activity & nutrient cycling - Reduce losses of water during fallows
Low crop intensity#	Reduce the risk for a particular crop by maximising soil water at sowing by proceeding with a long fallow period.	Crops only sown when PAW > 80% of full profile Preference for higher value/profitability crops (e.g. cotton) and high fertiliser inputs to maximise yield	- Reduced crop frequency but high profitability per crop - Long fallow periods requiring large herbicide program and low ground cover risks
2. CROP DIVERSITY			
Limited crop options ^	*Only crops with higher direct profitability are grown*	*Crop options limited to main crops (e.g. wheat, barley, chickpeas, sorghum)* *< 3 wheat or sorghum crops grown in a row.* *No more than 1 legume crop in 3 years.*	- *Soil-borne pathogens increase* - *Limited weed control & herbicide choices*
Diverse crop options ^	Utilise a wider range of crops to manage the build-up and damage from soil-borne pathogens and weeds in cropping systems	Crop sequence must have 2 crops resistant to *P. thornei* in a row and/or no more than 50% of crops are non-resistant. Alternate in-crop mode of action from previous year	- Reduced pathogen populations - Increased soil biological activity & diversity - Alternate herbicide chemistry & hence slow HR onset
3. NUTRIENT SUPPLY STRATEGY			
Conservative nutrient supply^	*Manage synthetic fertiliser input costs*	*Crop fertiliser budget to achieve 50% of requirement for seasonal yield potential.*	- *Soil fertility declining and likely crop yield penalties in good seasons*
High nutrient supply ^	Background soil fertility is boosted and crops provided with adequate nutrients to maximise yield potential.	Crop fertiliser budget to achieve 90% of requirement for seasonal yield potential. Periodic organic amendments and P replacement	- Soil chemical & biological fertility is maintained or increased - Crops able to maximise their seasonal yield potential
High legume ^	Increase inputs of biological N from legumes in system to reduce fertiliser N inputs	Every second crop is to be a legume• Legumes with higher biomass & N fixation inputs preferred (i.e. Fababean > Chickpea)	- Reduced N fertiliser requirements - Altered weed & pathogen populations
4. SOIL QUALITY RESTORATION			
No soil restoration	*Grain crops only*	*Crop choice is not influenced by soil management objectives (e.g. cover)*	- *Soil quality declines and hence water capture and nutrient supply may limit system productivity*
Cover crops #	Cover crops used to restore soil cover, increase organic inputs and manage weeds and diseases	Cover crops after crops leaving low ground cover Brown manure (i.e. spray out) crops with yield < 50% of potential	- Reduced herbicide use - Reduce N inputs for crops in rotation - Altered weed and disease populations
Ley pasture #	Perennial ley pastures phases to rebuild soil organic matter, nutrient levels and build disease suppressive soil biology.	A phase of grass and/or legume based pastures are sown in rotation with grain crops	- Reduced herbicide use - Reduce N inputs for crops in rotation - Altered weed and disease populations

^ indicates system strategies explored in factorial combinations and # indicates only partial factorials or singular treatments.

Underpinning each system strategy are a set of management 'rules' upon which to guide the decision-making within that system. Details of these are documented in Table 1. This 'rule-based' approach was preferred because it ensures the agronomic decisions being made in the system better reflect the drivers of the cropping program for the region, rather than being them determined inflexibly. The importance of soil water as a driver for crop sowing decisions was a critical element of these systems and hence is highly reliant on the rainfall, evaporation and temperatures recorded during the experiment. Furthermore, rather than crop sequences being specified at the outset, the rules specifying future crop choice along with crop history dynamically drive the crop sequence that emerges under a particular system. Thus the crop sequence is an emergent result of both the *system strategies* being employed and the *climatic conditions* over which the experiment runs. Systems modelling will then be used to complement the experimental program to explore how each of the strategies being tested would have performed across a different set of climatic conditions.

Challenges or limitations of this approach

This experimental approach will not allow direct comparison of individual crop responses to management inputs or crop sequences, because it can't be guaranteed that a common crop will be sown in a particular year. Similarly, metrics for system productivity or efficiency must be able to account for a diversity of crops grown at different times. Hence it is required that systems are compared in terms of their relative performance, such as $ returns/ha/mm, crop equivalents/ha, and kg grain N per kg fertiliser N input. Because the actual management of crops across various environments will not be consistent, this also requires that the systems are compared relative to a set of key benchmarks at each location.

The treatments being implemented will quantify the scale and nature of system changes rather than identify the optimal set of practices for specific environments. Each of the systems employ strategies or interventions that are chosen to test their consequences to the soil-plant-water system but these strategies are likely to be more extreme than what might be considered the normal boundaries of current practice. Hence, the findings will indicate the degree that the system modifications might affect multiple aspects of the farming system. Similarly, the farming systems experiments themselves won't take into consideration crop market conditions or volatility, the human aspect of decisions about what crop to plant, or the capital investments required. Price driven crop choice was considered as a system treatment but was discarded from the experimental set as it was not clear what system attributes this would influence. Economic analysis of experimental outcomes can be applied subsequently.

Conclusion

We propose that taking a rule-based approach to farming systems research is an effective way of representing the relative advantages and disadvantages of deploying different strategies and their interactions within a complex farming system. A further advantage of this approach is that the 'rules' and management practices that underpin each farming strategy can evolve over-time as new information or technologies are developed. This enables the systems being compared to remain relevant to current farming practices.

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