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.

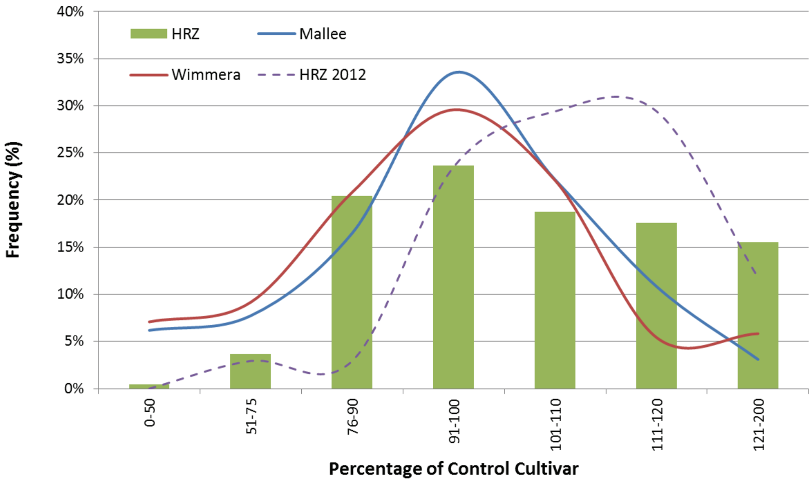

Figure 1: Measured grain yields relative to a control variety (100%) at NVT sites. Selected sites represent a rainfall zone: low rainfall zone (Birchip) n =194, medium rainfall zone (Horsham) n=240, HRZ (Hamilton & Streatham) n=245 (2002 – 2012). HRZ 2012 shows field experiments treated with fungicides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

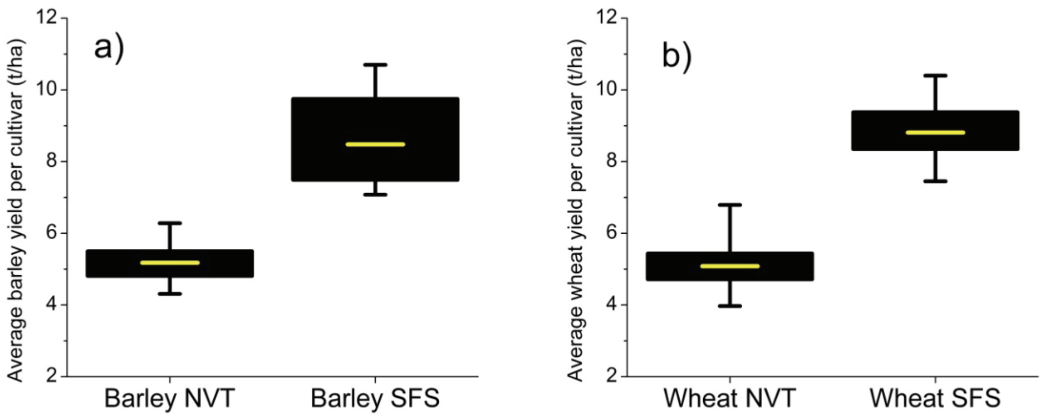

Figure 2: Box and whisker plot (maximum, 75 percentile, mean, 25 percentile, minimum) average 2013 grain yields per variety at National Variety Trials (NVT) site and nearby Southern Farming System (SFS) site for a) barley (NVT site at Teesdale (n=22) and SFS site at Inverleigh (n=13)) and b) wheat (NVT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

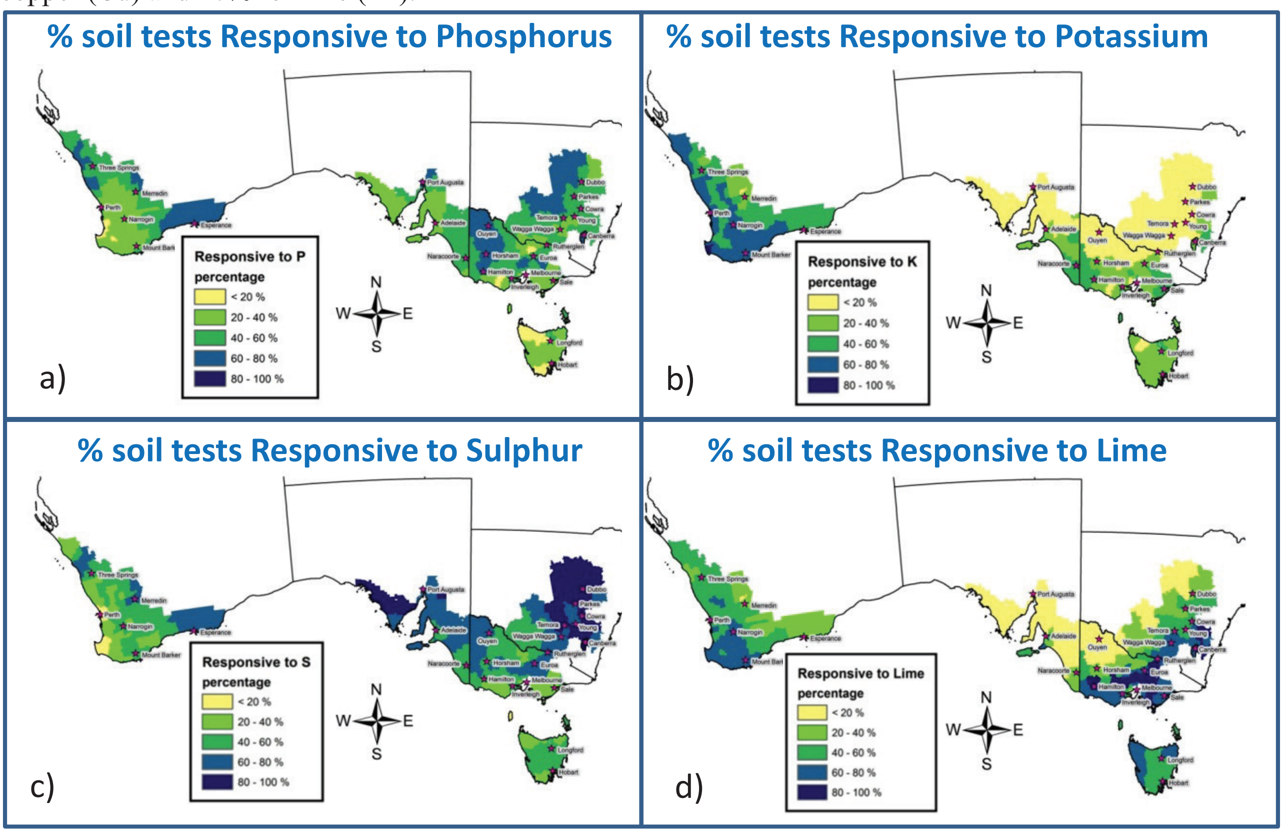

Figure 3: Spatial distribution of the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') to a) phosphorus b) potassium c) sulphur and d) lime based on the soil test data collated as part of the NLWRA nutrient database. (Available at 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
Funding was provided by GRDC and DEDJTR. We thank Jon Midwood from the Southern Farming Systems for encouraging help in our study.

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