Managing crop inputs in a high yield potential environment – HRZ of southern Australia

Grains Research & Development Corporation

IPNI International Plant Nutrition Institute

SFS

State Government Victoria

Managing crop inputs in a high yield potential environment – HRZ of southern Australia

Brendan Christy[1], Angela Clough[1], Penny Riffkin[1], Rob Norton[2], Jon Midwood[3], Garry O'Leary[1], Kerry Stott[1], Anna Weeks[1] and Trent Potter[4]

[1] *Department of Economic Development, Jobs, Transport & Resources*
[2] *International Plant Nutrition Institute (IPNI)*
[3] *Southern Farming Systems (SFS)*
[4] *Yeruga Crop Research, Naracoorte*

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Executive Summary

The high rainfall zone (HRZ) of southern Australia has the potential to produce far higher grain yields for wheat and canola than are currently achieved. A key criteria for achieving high grain yields is for crops to have access to adequate nutrition.

Information attained from growers and consultants in interviews leads to the conclusion that for a variety of reasons farmers are targeting yields of around 5 t ha^{-1} (far less than their potential) and are applying a level of inputs commensurate with that yield target. Up-front input costs are high, and with fertiliser application being the highest variable cost in a cropping enterprise, there appears to be a reluctance to apply higher levels of fertiliser to close the gap between actual and potential grain yields. Data collated in this report indicates that the key barrier limiting current nutrient application rates is growers and advisers lacking confidence that using higher application rates will result in an economic return on investment. Their lack of confidence stems from the knowledge gaps around the cost and responses of applying additional nutrient inputs to wheat and canola in crops with high grain yield potential. This report identifies the gaps in current knowledge that limit the ability of growers and advisers in the HRZ to confidently predict the additional nutrient inputs required by crops and the associated economic risks.

Crop yield potential

The HRZ of southern Australia has high yield potential with grain yields for wheat estimated at 4.5 t ha^{-1} in W.A. to 11 t ha^{-1} in south eastern Victoria and 3 t ha^{-1} to 5 t ha^{-1} for canola depending on location (Zhang *et al.* 2006; 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.

Some of this unrealised potential with current varieties is not being achieved due to nutrient inputs being lower than required to achieve maximum grain yields. Additional reasons for these relatively low yields are poorly adapted germplasm, periodic waterlogging, soil acidity, disease and sub optimal management. Currently many advisers are relatively new to cropping in the HRZ and have varying levels of knowledge and support in making recommendations. Often advisers do not feel adequately equipped to confidently assess crop demands and limitations, predict yield potential or the risks associated with high input systems in a variable climate. Consequently, recommendations are often conservative, leading to unrealised potential yields, low protein content and thus lost opportunity for growers.

Current nutrient status in the HRZ

A situation analysis of the soil nutrient status across the HRZ of southern Australia indicates a range of different nutrient deficiencies in different regions. An analysis of nutrient soil test data from the National Land and Water Resources Audit (NLWRA) shows that nutrient status for each nutrient varies, with large areas of land indicating that they are likely to be responsive to the application of phosphorus (P), potassium (K), sulphur (S) and lime (Figure 1). 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) suggests that these spatial images are conservative in their prediction 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).

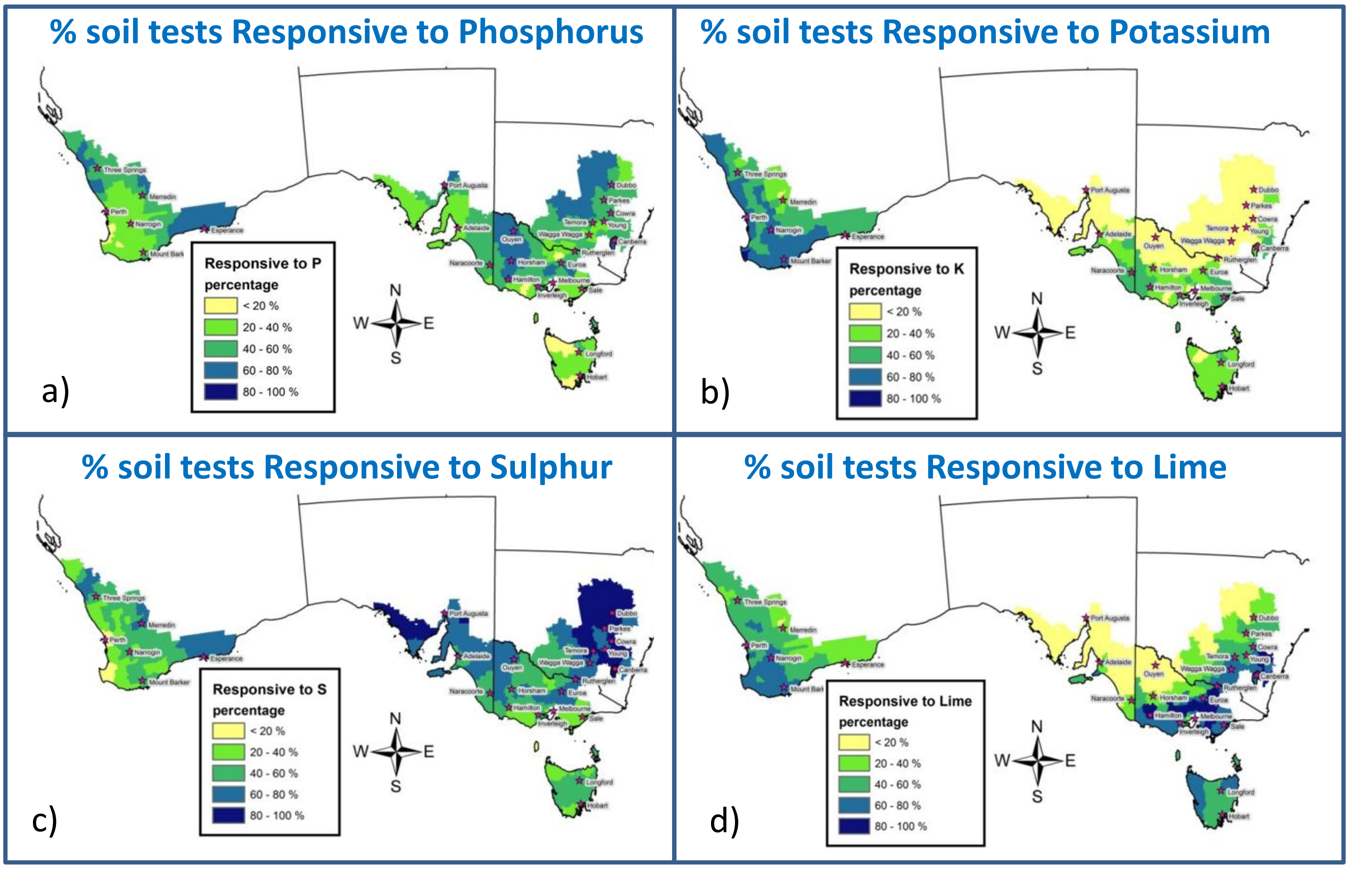

Figure 1: Spatial distribution of the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') to a) phosphorus b) potassium c) sulphur and d) lime based on the soil test data collated as part of the National Land and Water Resources Audit nutrient database.

Input costs and yield targets in the HRZ

Balancing all inputs including fertility is essential for optimizing yields, increasing profits, and improving the efficiency of fertiliser applications. Nitrogen (N) may be the most common limiting nutrient, however without balanced nutrition, fertiliser N applications may be less efficient, and part of the fertiliser investment is wasted. Fertiliser is the largest single variable cost for grain producers, amounting to 15-20% of all cash costs, or 20-25% of variable costs (Rural Solutions 2012).

Limited understanding of the benefits and risks of using higher application rates can be overcome by actively engaging growers and advisers in research using a Participatory Action Approach. Research that fills the gaps in agronomic and economic knowledge for the whole of the HRZ needs to use a combination of field experiments, biophysical modelling and economic modelling. The aim of such research would be to produce tools that enable growers and advisers to predict their expected grain yields and enable them to link expectations to cost, season variation, site variation, profitability and economic risk.

The overall outcome of implementing this type of research would be that advisers can make informed decisions using the tools developed to predict the input requirements which match the yield expectations for wheat and canola while understanding the costs and returns, variability (seasonal and location) and risks associated with their yield target.

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Background

This report collated current knowledge and identified the knowledge gaps which limit the ability of growers and advisers to confidently predict input requirements and associated risks for crops with high yield potential in the cropping high rainfall zone of southern Australia (HRZ). The overall purpose of this work was to provide recommendations for an experimental and modelling GRDC project which can more accurately predict nutrient demands whilst also quantifying the economic risks associated with applying inputs to crops to allow the achievement of their high yield potential. This report contains the assembled background information used to produce the project logic of the GRDC project submission. It is structured into three sections which detail within the HRZ the: 1) Crop yield potential, 2) Current soil nutrient status and 3) The costs and yield response of crop nutrient inputs.

Situation Analysis – Crop yield potential

How close are current grain yields to their yield potential in the HRZ?

The High Rainfall Zone (HRZ) of southern Australia has high yield potential with grain yields for wheat estimated at 4.5 t ha^{-1} in W.A. to 11 t ha^{-1} in south eastern Australia (Gardner *et al.* 1983; Zhang *et al.* 2006; Acuña *et al.* 2011; Sylvester-Bradley *et al.* 2012) and 3 t ha^{-1} to 5 t ha^{-1} for canola depending on location (Zhang *et al.* 2006; 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 from 1996-2001 in Western Australia (Hill *et al.* 2005). An analysis of data from National Variety Trials (NVT) over the past 10 years in Victoria shows grain yields for both wheat (Figure 2) and canola (Figure 3) to be generally below the predicted potential. Variety testing in South Australia for wheat (Figure 4) and canola (Figure 5) demonstrate a similar pattern.

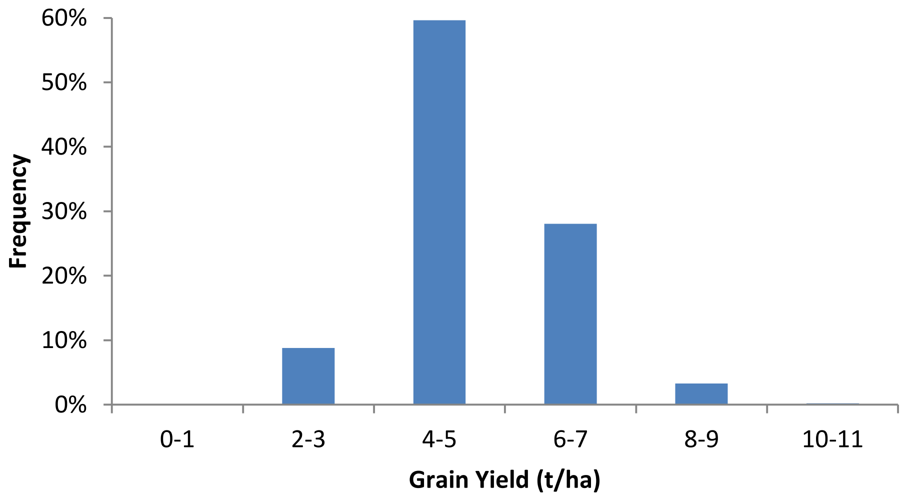


Figure 2: Frequency distribution of wheat grain yields from National Variety Trials (NVT) in Victoria (Inverleigh, Hamilton, Streatham and Rutherglen) from 2002-2012 (excluding 2006 & 2009), n=488

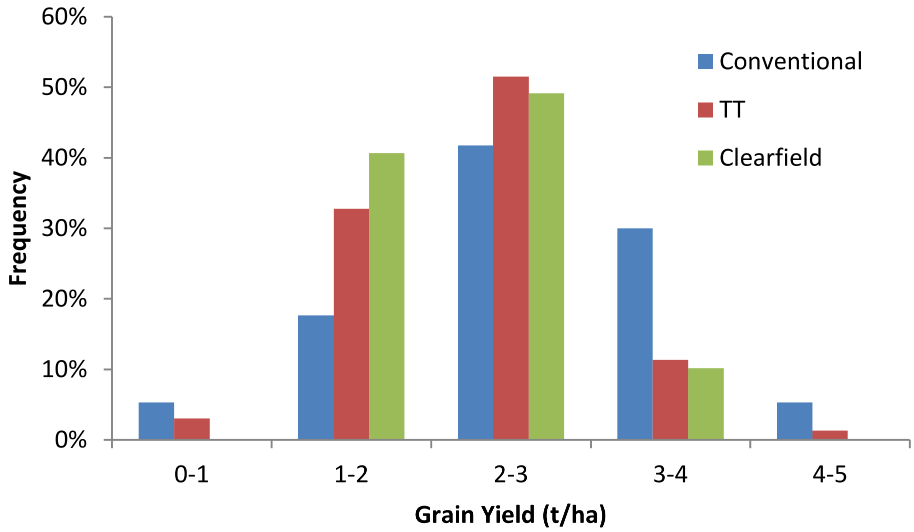


Figure 3: Frequency distribution of canola yields from NVT in Victoria (Inverleigh, Hamilton, Streatham and Rutherglen) from 1999-2012 (excludes 2006 & 2009) for conventional (n=170) and triazine tolerant (TT, n=229) and from 2007-2012 for Clearfield varieties (n=59).

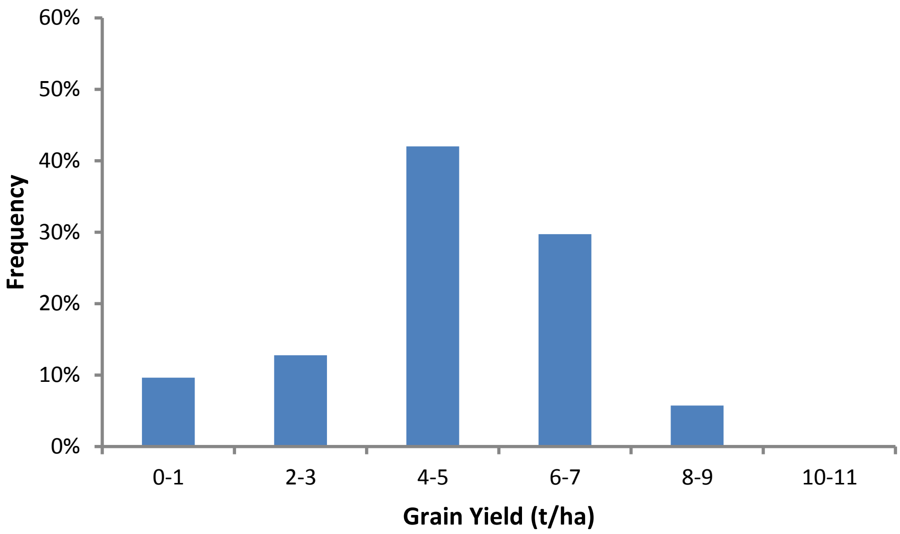


Figure 4: Frequency distribution of wheat grain yields from wheat variety trials in South Australia (Conmurra, Frances and Millicent) from 2005-2011, n=955

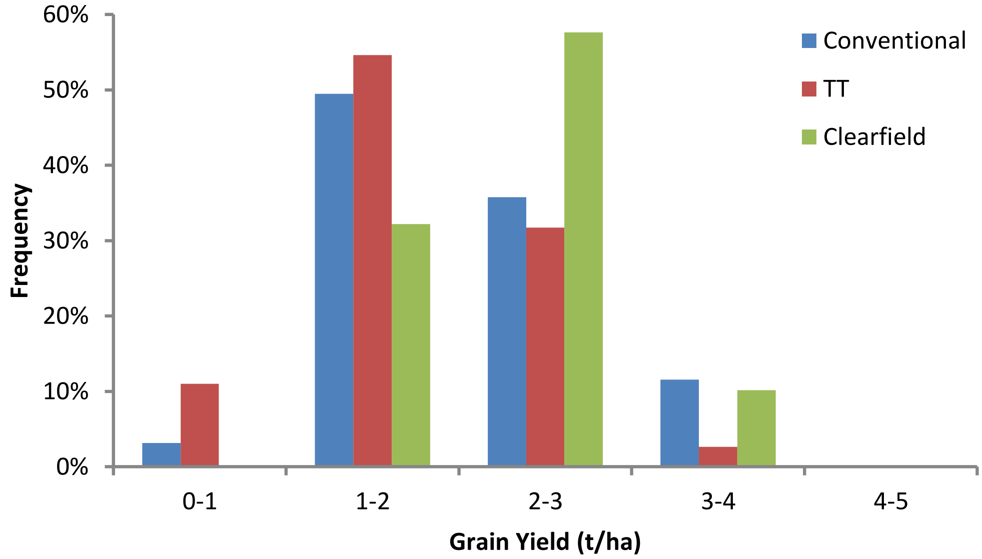


Figure 5: Frequency distribution of canola yields from canola variety trials in South Australia (Bool Lagoon and Frances) from 2006-2012 for conventional (n=95) and triazine tolerant (TT, n=227) and from 2008-2012 for Clearfield varieties (n=59).

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 6). 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 predicted 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 theoretical wheat yield of 8 t ha^{-1} can be raised at least to 12 t ha^{-1} through the provision of adequate crop inputs to crop ideotypes specifically bred for the HRZ environment.

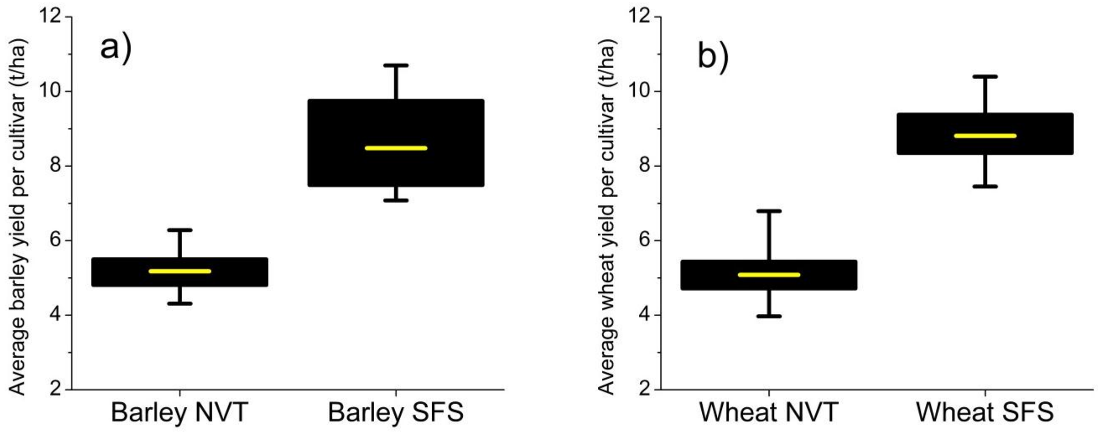


Figure 6: Box and whisker plot (maximum, 75 percentile, mean, 25 percentile, minimum) average 2013 grain yields per variety at National Variety Trials (NVT) site and nearby Southern Farming System (SFS) site for a) barley (NVT site at Teesdale (n=22) and SFS site at Inverleigh (n=13)) and b) wheat (NVT site at Streatham (n=32) and SFS site at Westmere (n=22))

What is preventing this yield potential from being reached?

A key reason for the yield potential of current varieties not being achieved is that inputs are lower than is required to achieve maximum grain yields. Additional reasons for these relatively low yields are poorly adapted germplasm, periodic waterlogging, soil acidity, disease and sub optimal management. Currently many advisers are relatively new to cropping in the HRZ and have varying levels of knowledge and support in making recommendations. Often advisers do not feel adequately equipped to confidently assess crop demands and limitations, predict yield potential or the risks associated with high input systems in a variable climate. Consequently, recommendations are often conservative, leading to unrealised potential yields, low protein content and thus lost opportunity.

Germplasm

In the HRZ, varieties available to growers have generally been introduced from other regions with little breeding specifically for HRZ. Current research is providing evidence that significant gains in yield potential can be achieved through germplasm improvement that takes advantage of natural resources in the HRZ (Sylvester-Bradley et al 2012). This potential for higher grain yields due to genetic gains of wheat in the HRZ, is demonstrated by the NVT data (Figure 7). 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 7). This is even more evident when experiments are treated with fungicides to eliminate foliar disease as a constraint to grain yield (shown in Figure 7 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 little 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.

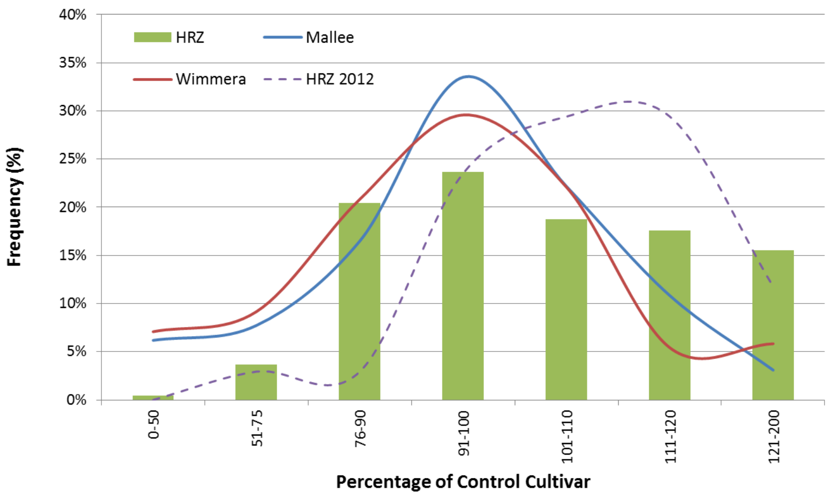


Figure 7: Comparison of measured grain yields relative to a control variety (100%) at NVT sites. Selected sites represent a rainfall zone: low rainfall zone (Birchip) n =194, medium rainfall zone (Horsham) n=240, HRZ (Hamilton & Streatham) n=245 (2002 – 2012). HRZ 2012 shows field experiments treated with fungicides in 2012 (Inverleigh and Rutherglen) n=34.

Nutrition

The protein levels of wheat from NVT trials in Victoria (2002–2012, excluding 2006 and 2009 due to crop failure) provide evidence of sub-optimal nutrition (Figure 8). 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 (Figure 8) and suggest that N may have been limiting in these field experiments. Screenings were also low (Figure 9) indicating that the crops had adequate soil moisture over grain filling period and did not 'hay off'. The low screenings also indicate that the field experiments were not adversely effected by crop disease. This is an important qualification as NVT varieties sown in Victoria were not routinely treated with fungicides to control foliar disease until 2010.

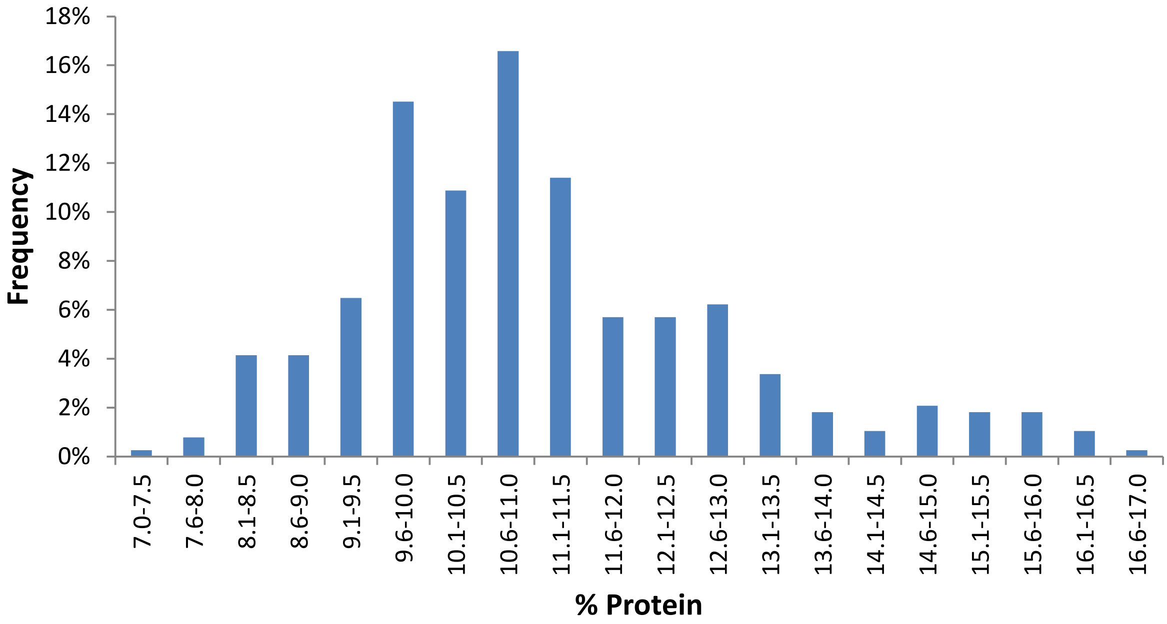


Figure 8: Frequency of % protein in wheat from NVT trials in Victoria (Inverleigh, Hamilton, Streatham and Rutherglen) from 2002-2012 (excluding 2006 & 2009), n=386

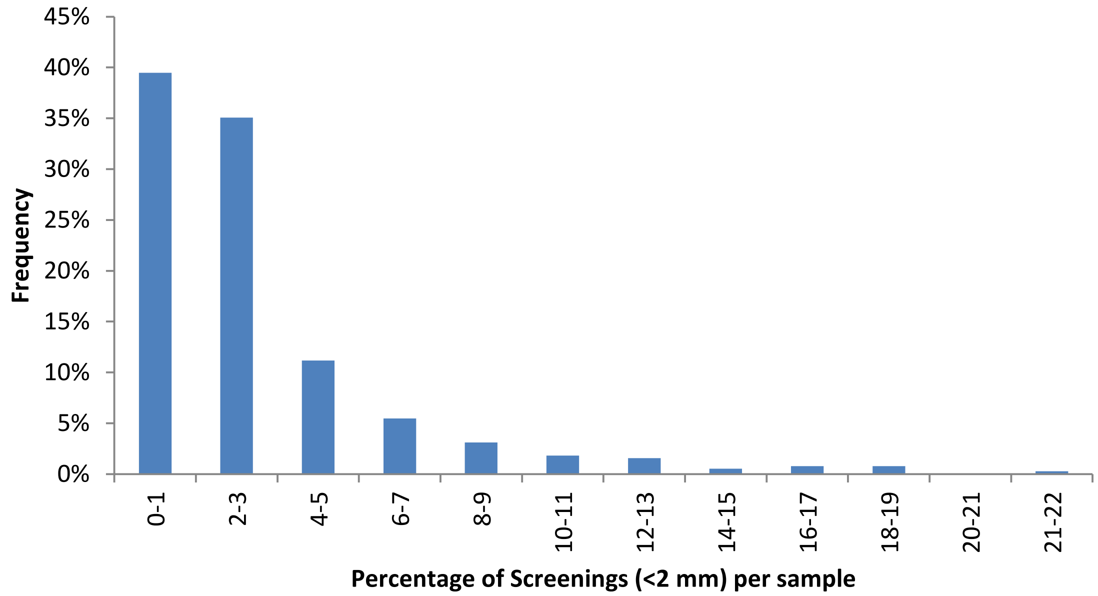


Figure 9: Frequency of screenings (screen sieve 2 mm) in wheat from NVT trials in Victoria (Inverleigh, Hamilton, Streatham and Rutherglen) from 2002-2012 (excluding 2006 & 2009), n=385

Environment

Factors constraining current yields can vary greatly across the HRZ depending on soil type, climate and seasons, highlighting the need for an integrated package of grower recommended packages, targeted specifically to the local site specific problems faced. For example, although canola was found to be constrained by end-of-season water supply in New South Wales (NSW) (Lisson et al. 2007), the other states in the south-eastern (SE) HRZ (South Australia, Victoria and Tasmania) suffered limited water stress during grain filling as is indicated by crop harvest index (Figure 10). Returns for inputs targeting high yields may therefore not necessarily be realised in NSW due to unfavourable climatic conditions, however in other regions management decisions and/or input limitations are limiting yields. Inputs therefore need to be matched not to the maximum yield potential but to the achievable yield and the likely returns (the economic potential). Any tools developed for use by grower and advisers to help in their understanding of how levels of input determine crop potential need to account for the diverse range of limiting factors across landscapes along with seasonal variations to improved their understanding of the risks involved.

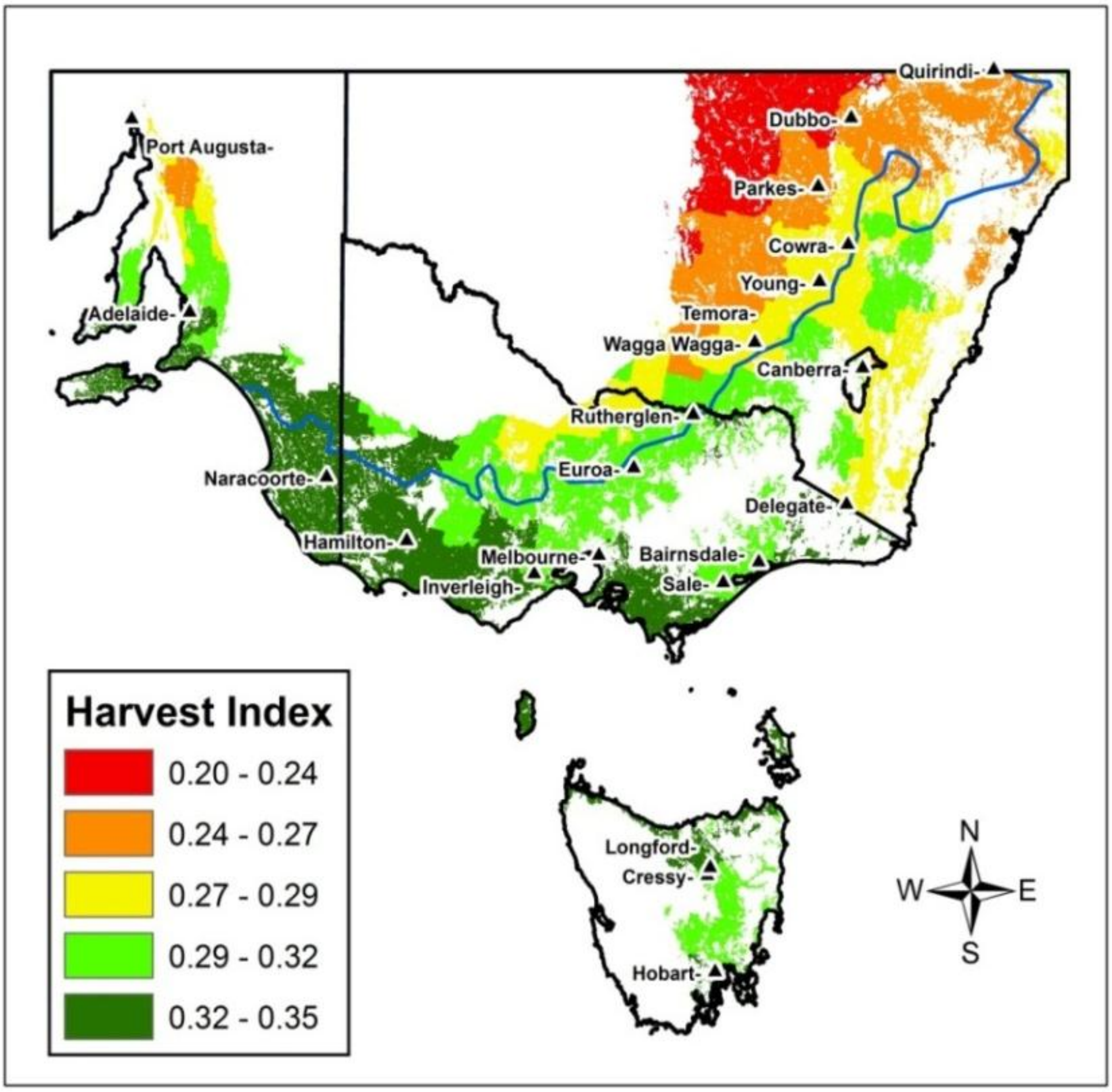


Figure 10: Average harvest index (maximum harvest index = 0.35) for spring-short (Hyola50) due to water stress from anthesis to harvest. Blue contour line shows where averaged April-October rainfall equals 400 mm/year (Christy *et al.* 2013).

Situation analysis - Current nutrient status in the HRZ

In 2001, the federal government published an "Australian Agricultural Assessment", as part of a National Land and Water Resources Audit (NLWRA). This included an assessment of nutrient management in Australian agriculture including a farm-gate nutrient balance for N, P, K, S and Ca (Audit 2001). The data is publically available, covering the audit period around 1994 to 1996 and provided a snap-shot of the current status of potential nutrient deficiencies in the HRZ. There has been no more data added to the database since the period of the audit.

This section of the report presents a situation analysis of individual soil nutrients to determine what locations within the HRZ are responsive to additional nutrient inputs. The maps shown in this report use data sourced from NLWRA and are categorised within the ABS statistical local areas as responsive using the critical values for each nutrient determined by the NLWRA.

Since that time farming systems have altered, Australia has been through the millennium drought, commodity prices have altered and there has been increasing interest in the interaction of nutrients in the environment. Also, critical values have since been redefined in terms of potential fertiliser response by different crops and soil types by the Better Fertiliser Decision for Crops National Database (BFDC). This database was developed to bring together rate of fertiliser experiments for use in developing crop calibration relationship for a range of nutrients (Watmuff et al. 2013). This report presents data from the BFDC to analyse crop response to varying levels of nutrients in the HRZ. However it was not possible to use this data to redefine the spatial maps presented in this report due to the large number of soil types with no critical value determined. Future additions of experimental data to the BFDC, the inclusion of this additional information would increase our understanding of the current status of nutrient requirements for crops in the HRZ, although we do not expect that the overall conclusions arrived at in this report would be altered by this additional information.

The potential gains in grain yields through correction of nutrient deficiencies indicated through mapping soils using the data from the NLWRA need to be tempered with the understanding that other constraints to crop production may override potential gains for correcting a mapped single nutrient deficiency. Weaver and Wong (2011) showed that small gains in grain yield would be attained by applying P alone to 63% to 89% of soils under pasture or crop despite soil P being less than critical values. This discrepancy is due to over 50% of the samples having indications of overriding constraints (soil acidity, potassium and sulphur deficiency) to yield.

Phosphorus

Phosphorus (P) deficiency in both pastures and crops in southern Australia has long been recognised as an issue. To overcome this limitation most agricultural soils have a long history of P application (McLaughlin *et al.* 2011). A significant proportion of winter cereal production costs in many parts of the world is phosphorus fertilisers (Bell et al. 2013). Wheat grain yield is impacted by phosphorus deficiency by depressing early growth, leaf emergence rate, and maximum rate of tiller emergence (Rodríguez et al. 1999). Both top and root growth of canola is restricted by phosphorus deficiency with severe deficiencies leading to poorly developed roots systems, thin stems with few branches and small, narrow leaves (Grant and Bailey 1993).

Across Australia, a number of soil tests are used to estimate P fertiliser rates for crops. The Colwell soil phosphorus test is the most widely used soil P test in Australia. The Olsen soil P test (which uses the same extractant (calcium carbonate), but a much reduced extraction time) is mainly used in Victoria and Tasmania. Because more P is extracted by the Colwell test, different interpretation guidelines must be used for each test (Moody and Bolland 1999). Interpretation criteria for any soil P test also needs to be related to the soil's P buffering capacity (PBC), however, PBC is not analysed routinely by Australian soil testing services. As both the Colwell and Olsen method use a calcium carbonate extractant their use in interpreting phosphorus response on Calcarosols (Isbell 1996) is difficult due to the high carbonate content of these soils. An alternative method suited for Calcarosols termed the DGT (Diffuse Gradient in Thin-Films) method is currently being commercialised which will improve phosphorus requirement interpretation for these soils (Mason *et al.* 2010).

By using all phosphorus soils tests which reported a soil texture in the NLWRA database (n=224,674) a spatial map of the percentage of soil tests which are responsive to additional P was determined (Figure 11). This potential response was based on the diagnostic ranges for Colwell P and Olsen P (Table 1). This analysis indicates that most regions were found to have a considerable number of soils which are P deficient. The percentage number of soil tests found to be responsive to P includes all agricultural enterprises within the SLA including horticultural, grazing and dairy farms as well as cropping properties.

Table 1: Diagnostic P range used for soil tests (From National Land and Water Resources Audit)

Soil Test	Soil Type	Low	Marginal	Adequate	High
Colwell P	Clay	<20	20-29	29-35	>35
	Clay Loam	<15	15-24	24-30	>30
	Loam	<15	15-24	24-30	>30
	Sandy loam	<10	10-19	19-25	>25
	Sand	<10	10-19	19-25	>25
Olsen P		<8	8-12	12-18	>18

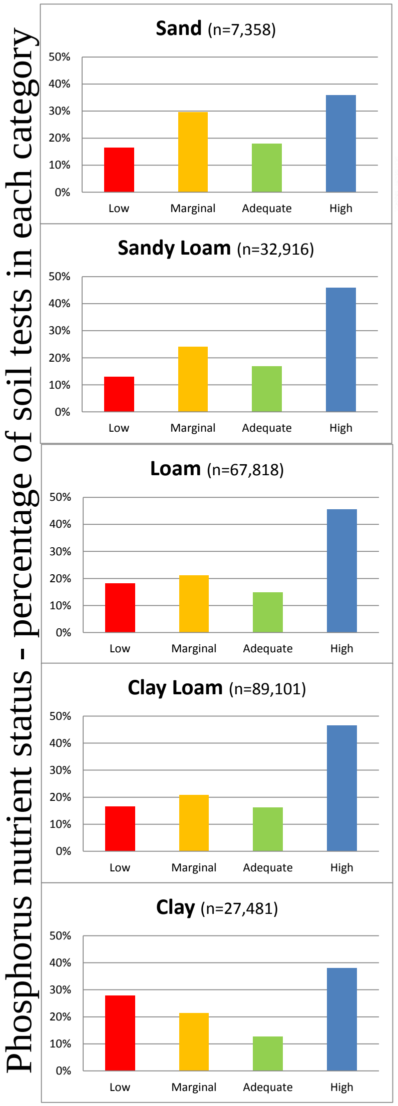
A nutrient analysis of grain harvested from the GRDC National Variety Trials (NVT) program in 2008 and 2009 (Norton 2012), found grain P concentrations were higher on average than the critical value for P concentration (2700 mg kg^{-1}) given by Reuter et al (1997b) for Australian wheat grown in the field (Table 2), demonstrating adequate soil P. The adequacy of P availability for wheat grain production in the HRZ is based on current grain yields of 2-4 t ha^{-1}, however the potential wheat yield in this zone is 8-10 t ha^{-1}. It is not known whether grain concentrations of P would still be adequate when wheat yields of about 8-10 t ha^{-1} are being achieved in the HRZ.

Table 2: Average P concentrations of grain from National Variety Trials (NVT) conducted in 2008 and 2009

Region	P (mg kg^{-1})
Southeast NSW	3613 (+/- 202)
Lower Eyre Peninsula SA	3075 (+/- 165)
Southeast SA	3620 (+/- 181)
Northeast Victoria	2950 (+/- 286)

Data for southwest Victoria not provided

Building up phosphorus availability in the soil takes a long time. For example the Dahlen long term fertiliser experiment near Horsham found that Colwell rises 0.2 mg kg^{-1} for each kg P over the P balance (IPNI 2012) giving an indication of the rate of P fixation in these soils. So if we put on 5 kg extra of P, the Colwell would rise 1 mg kg^{-1} and the rest would go into non-labile pools.



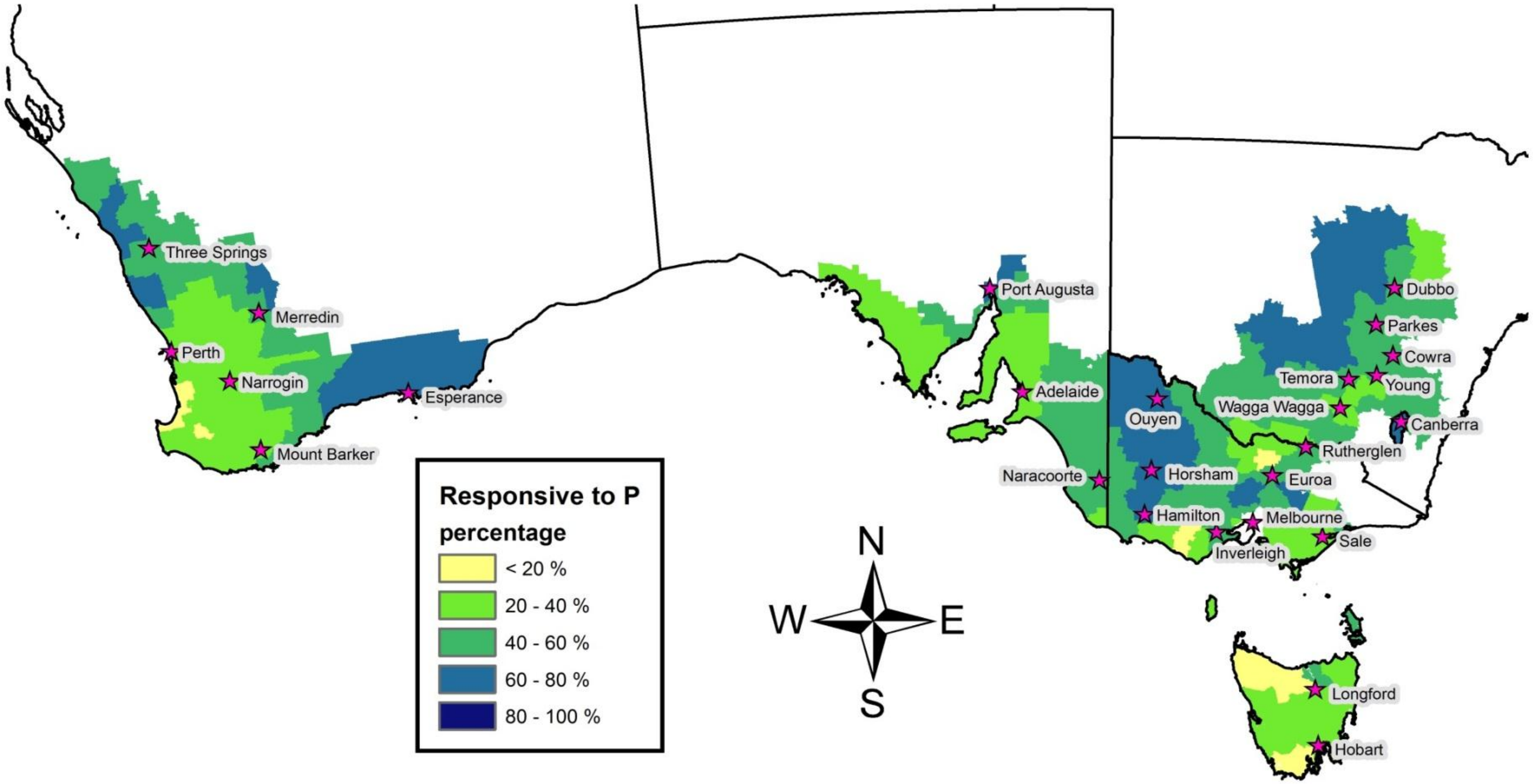


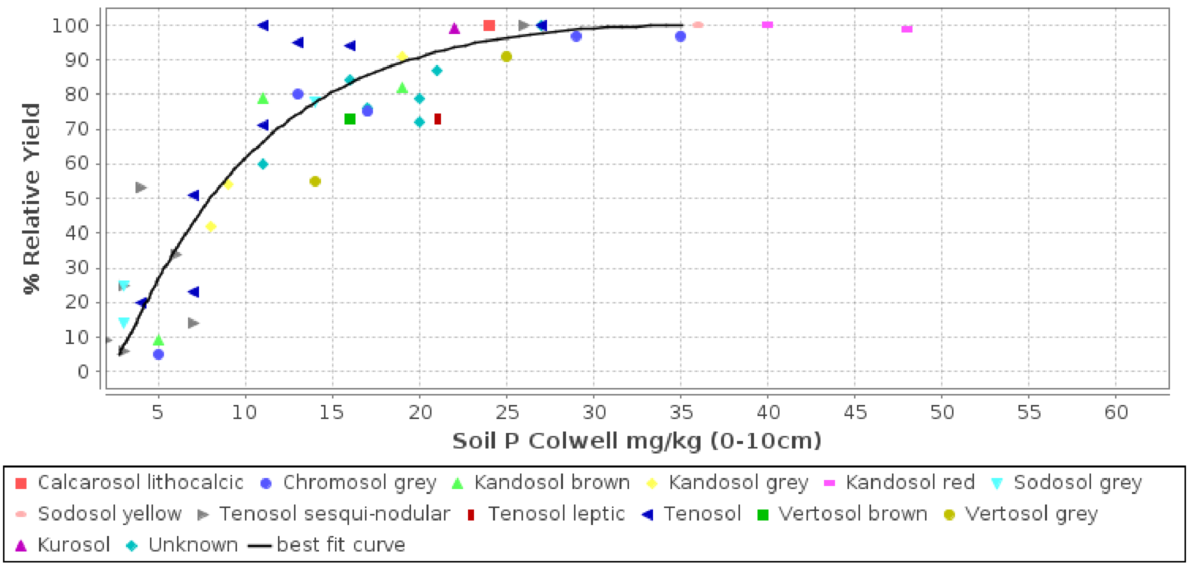
Figure 11: The bar charts show the percentage of tests in each category range per soil type based on diagnostic ranges defined in Table 1 and the spatial map shows the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') in the National Land and Water Resources Audit nutrient database.

An analysis of wheat data in the Better Fertiliser Decision for Crops National Database (BFDC) database for all of Australia shows that Colwell P (no PBI) is well correlated to grain yield for some soil types (all Chromosols except red, red Sodosols and all Vertosols except grey) but not for others (most Calcarosols and grey Vertosols) (Bell *et al.* 2013). However, the data specific to south-eastern Australia demonstrates poor overall correlation in this region between Colwell P and grain yield for the key soil types (Table 3). A further restriction of the data to sites in the HRZ (over 450 mm growing season rainfall in the year of the experiment) reduced the number of treatments to 10 and increased the critical value for 90% maximum grain yield to 30 mg P kg^{-1} with broad range (11-81 mg P kg^{-1}) and poor correlation (r = 0.41). A factsheet recently produced (GRDC 2014) summarizes the range of critical values per soil type (Isbell 1996) that could be defined based on Better Fertiliser Decision for Crops National Database.

Table 3: Data for Colwell P (0x10 cm layer) with wheat from the Better Fertiliser Decisions for Crops database for all of south-eastern Australia under rain fed, winter wheat production (Data with severe crop stress rating excluded). Critical concentrations and confidence intervals apply to 90% relative grain yield (GY). Data sourced from http://www.bfdc.com.au/frontpage.vm on 15 January 2014.

Soil order	Treatment series	Critical concentration (mg P kg^{-1})	Confidence interval (mg P kg^{-1})	R value
Chromosol	79	27	19-38	0.39
Sodosol	78	30	21-45	0.44
Vertosol	41	20	14-27	0.35

There are limited soil P test results in the BFDC database for canola grown under rain fed conditions as a winter crop in south-eastern Australia (21 for Colwell P at 0-10 cm depth) however the values are well correlated to grain yield (R = 0.89) and the range of soil P values that produce 90% maximum grain yield is small (17-22 mg P kg^{-1}) (Figure 12).



Soil test calibration:

80% Relative Yield: 15.0 (13.0 - 17.0)

90% Relative Yield: 19.0 (17.0 - 22.0)

95% Relative Yield: 23.0 (20.0 - 27.0)

Correlation R: 0.89

Slope RY(50-80): 4.3 (3.6 - 5.0)

Regression equation: $x = e^{(1.9182(\arcsin(\sqrt{y/100})) + 0.56952)}$

70% confidence limit at 90% Relative Yield: 19.0 (18.0 - 21.0)

Figure 12: Phosphorus response curve for canola using data extracted from the Better Fertiliser Decisions for Crops database (BFDC) for all of Australia under rainfed, winter crop production. Data is P as measured Colwell P in 0-10 cm layer Data sourced from (http://www.bfdc.com.au/frontpage.vm) on 20 January 2014. No DGT data available for canola in this region.

A spatial map of how these soil P critical values translate for wheat to the southern region of Australia covered by this report demonstrate that there are still considerable areas where critical values have not been determined due to soil type differences (Figure 13). For canola, the BFDC database determined a single Colwell P value of 18 mg kg^{-1} (GRDC 2014).

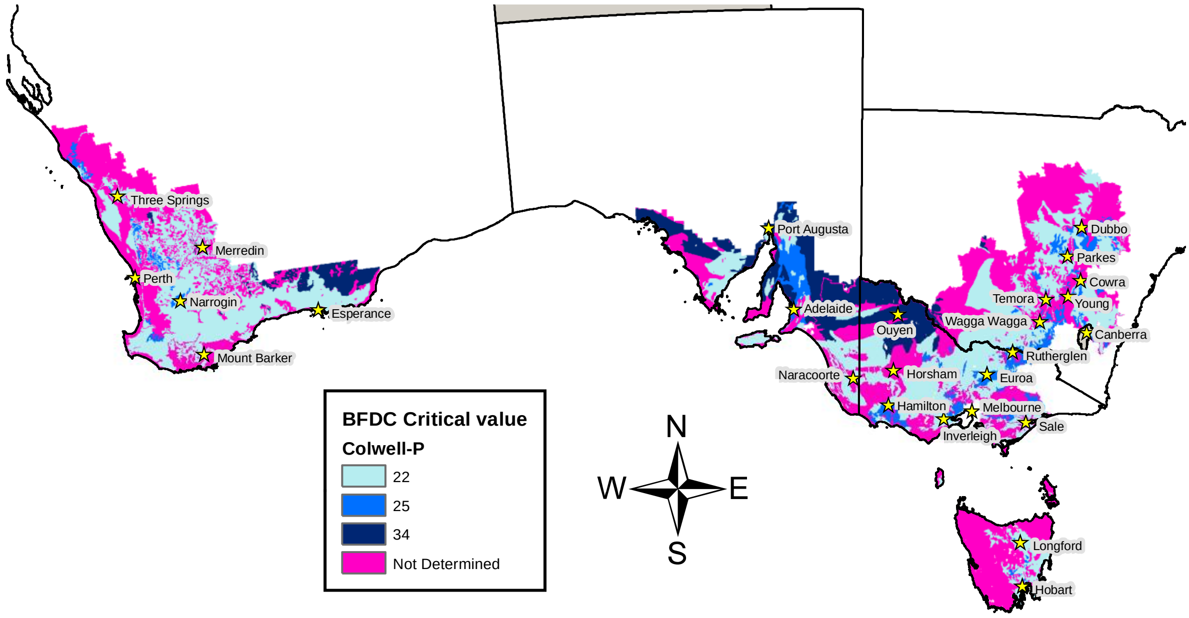


Figure 13: Spatial distribution of Colwell-P critical values (mg kg^{-1}) per soil type (Isbell 1996) defined by the BFDC Interrogator (GRDC 2014).

Potassium

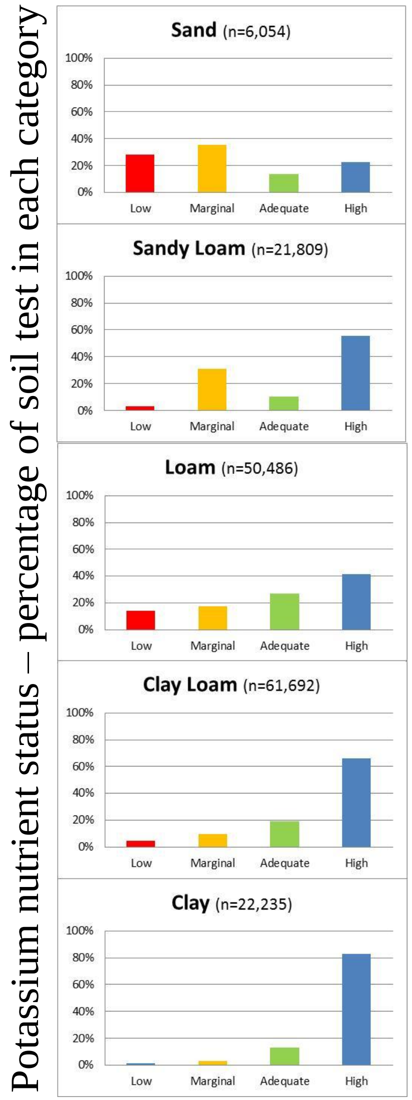
Although potassium fertilisers have been applied to pastures grown on K deficient soils for many years in Australia, their application for broad-acre crops has not been needed until recently. Historically K inputs in cropping systems across all regions of Australia have been low resulting in negative balances (Brennan and Bell 2013). On sandy duplex soils in Western Australia K deficiency of wheat became apparent in the early 1990s (Reuter *et al.* 1997a). The agricultural-induced deficiency of K has been attributed to leaching below root-zones and the removal of K in product (hay, silage) along with the redistribution by grazing animals. Most sandy soils in the WA region are now K-deficient for crop production (Brennan *et al.* 2004). Similarly, negative balances are common in all broad-scale cropping systems of eastern and northern Australia.

The commonly used Colwell, Skene and exchangeable K soil tests are strongly correlated to one another and therefore the national K soil test data were standardised to Colwell K values (Audit 2001). By using all potassium soils tests which reported a soil texture in the NLWRA database (n=162,276), and interpreted on a crop's potential to respond to K fertiliser (Table 4) a spatial map of the percentage number of soil tests which are responsive to additional K was determined (Figure 14).

Table 4: Potassium diagnostic range used for soil tests (mg kg^{-1}) 0-10 cm depth (From National Land and Water Resources Audit)

Soil Type	Low	Marginal	Adequate	High
Clay	<120 *	120-180	180-300	>300
Clay Loam	<110	110-160	160-250	>250
Loam	<110	110-160	160-250	>250
Sandy loam	<50	50-140	140-170	>170
Sand	<80	80-150	150-200	>200

*** Use this value with caution – high coefficient of variation (47%)**



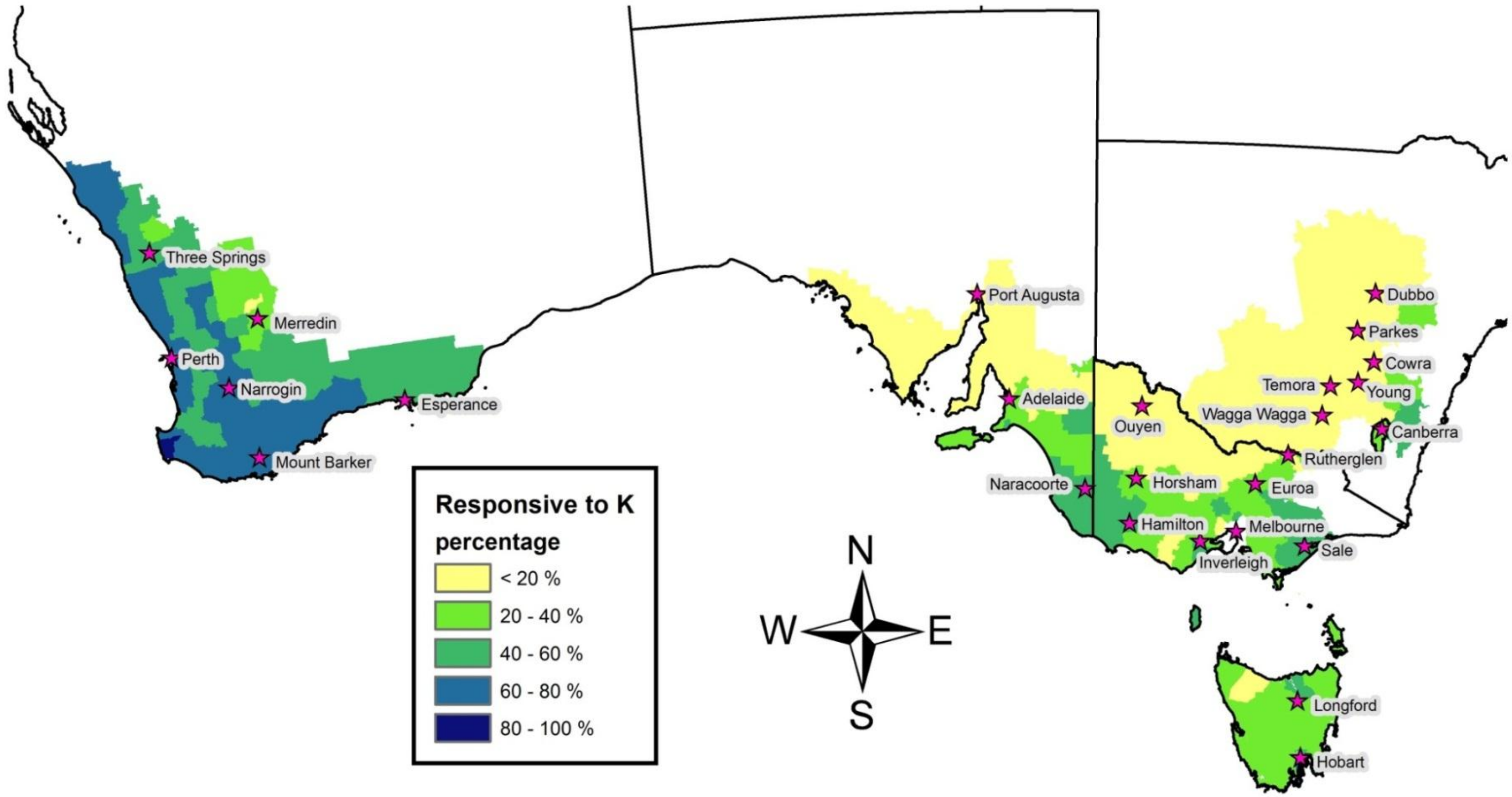


Figure 14: The bar charts show the percentage of tests in each category range per soil type based on diagnostic ranges defined in Table 4 and the spatial map shows the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') in the National Land and Water Resources Audit nutrient database.

The potential crop response to K indicated that most regions in WA were responsive to additional K fertiliser application. Additionally half the soils in the HRZ of Victoria, South Australia and Tasmania were responsive to K. A more recent analysis of soil test data was compiled from the Incitec Pivot soil test database for 2010, and this found that for the HRZ of Victoria and South Australia about half the sandy and loam soil types seem to have low K (below 0.31 cmol kg^{-1}) and therefore would achieve an additional crop response to additional potassium fertiliser, whereas on the heavier soils deficiency was not such a problem (Figure 15).

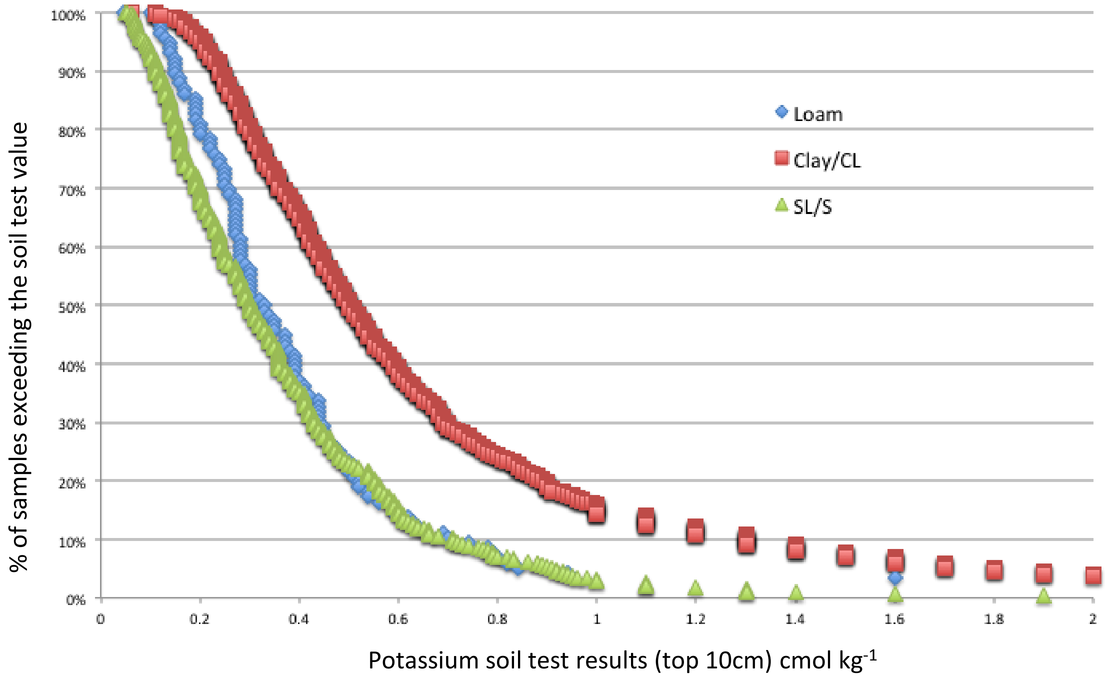


Figure 15: Compiled potassium soil sample results (n=1,957) compiled from data sourced from Incitec Pivot soil tests 2010 for the SA and Vic HRZ (Critical value for sand and loam 0.31 cmol kg^{-1} and for clay 0.56 cmol kg^{-1}). CL = Clay loam, SL = Sandy Loam, S = Sand.

Data from the BFDC database was used to derive the critical value for K in south-eastern Australia however, it was not possible to derive a critical values for the majority of the study region (Figure 16) including the HRZ of south-eastern Australia due to the lack of experiments that had a minimum 450 mm growing season rainfall. The R-value for the K crop response curve demonstrated that grain yield and soil test results are poorly correlated (r= 0.6) and the range of soil K values that relate to 90% maximum grain yield are broad (57-83 mg K kg^{-1}). There is no data in the BFDC database for canola in south-eastern Australia. All data pertains to Western Australia. The response curve of K for the whole of south-western Australia is correlated with grain yield (R = 0.69) and the critical value for 90% maximum grain yield is 47 mg K kg^{-1} in the 0-10 cm layer (range 43-53 mg K kg^{-1}). A factsheet recently produced (GRDC 2014) summarizes the range of critical values per soil type (Isbell 1996) that could be defined based on Better Fertiliser Decision for Crops National Database.

A spatial map of how these soil K critical values translate for wheat to the southern region of Australia covered by this report demonstrate that there are still considerable areas where critical values have not been determined due to soil type differences (Figure 16). For canola, the BFDC database determined a single Colwell K value of 45 mg kg^{-1}(GRDC 2014).

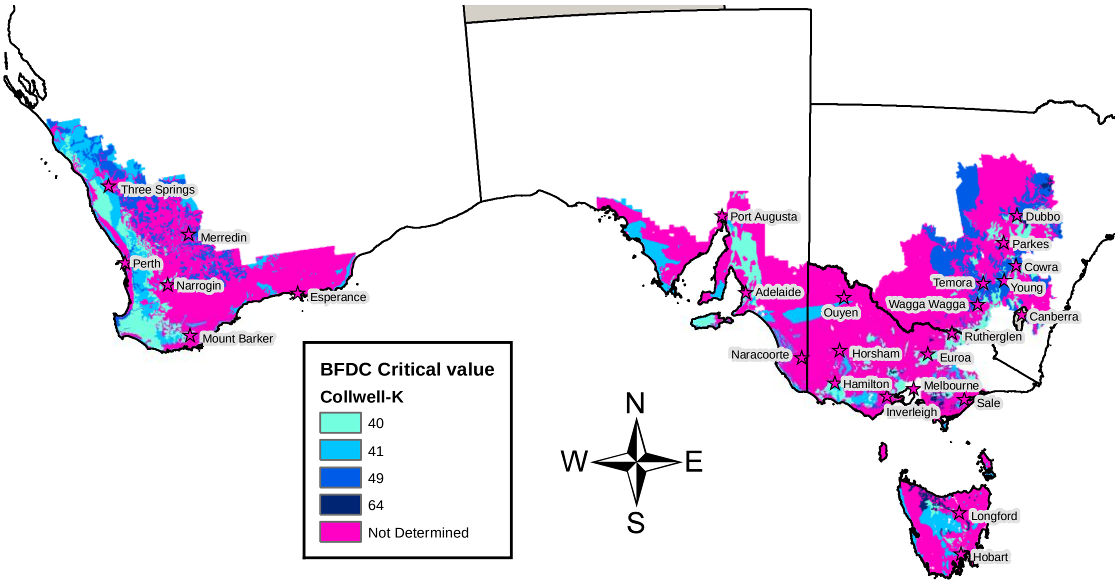


Figure 16: Spatial distribution of Colwell-K critical values (mg kg-1) per soil type (Isbell 1996) defined by the BFDC Interrogator (GRDC 2014).

Sulphur

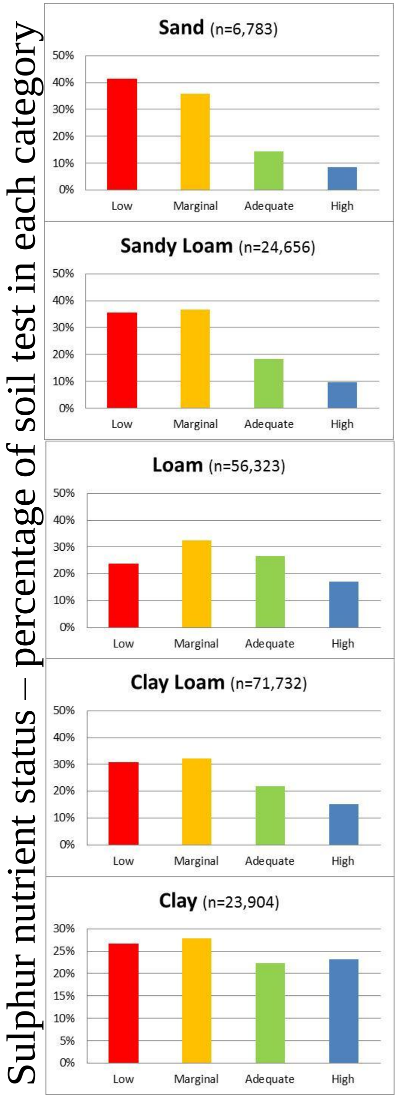
Soils deficient in sulphur (S) are historically dominated by pasture production and include Gippsland in Victoria, the Tablelands in New South Wales, coastal regions with higher rainfall in South Australia, and northern coastal regions of Tasmania (Blair and Nicolson 1975). The HRZ cropping region of south-eastern Australia is contained within this area, suggesting that cropping land within this regions faces S deficiencies. Known key cropping areas likely to be low in S are the deep sands of Western Australia, where soils are low in S due to leaching (Brennan and Walton 2006; Bolland and Russell 2009) and the sandy soils in the HRZ region of southeast South Australia.

Inadequate S in soils was largely addressed from the 1970s through to the 1990's by the regular use of superphosphate fertiliser (Lipsett and Williams 1971; Schultz and French 1976). Gypsum which is often used to mitigate the effects of soil sodicity, a constraint common in the Sodosols and Vertosols of southern Victoria, north-eastern Victoria and Riverine Plains also provides an additional source of S. However, only 20-30% of applied S is retained between years in soils located in the HRZ of south-eastern Australia due to leaching (Chen *et al.* 1999; McCaskill and Cayley 2000). The recent increase in the use of high-analysis fertilisers in the HRZ, which contain less than 1% S, may lead to an increase in sulphur deficiency especially for canola as found in southern and central NSW (Hocking *et al.* 1999).

Crops differ widely in their S requirement, typically greatest for brassicas followed by legumes, and then by cereals. Based on sulphur soil tests which reported a soil texture in the NLWRA database (n=183,398) a spatial map of the percentage number of soil tests which are deficient in S was determined (Figure 17), based on the diagnostic ranges for sulphur (Table 5). The analysis indicates that most regions were found to have a considerable number of soils which will respond to additional S fertiliser application. The northern regions in the HRZ of NSW indicated that almost all soils were responsive to sulphur.

Table 5: Sulphur diagnostic range for soil tests (0-10 cm KCl method) (National Land and Water Resources Audit)

Low	Marginal	Adequate	High
<5	5-10	10-20	>20



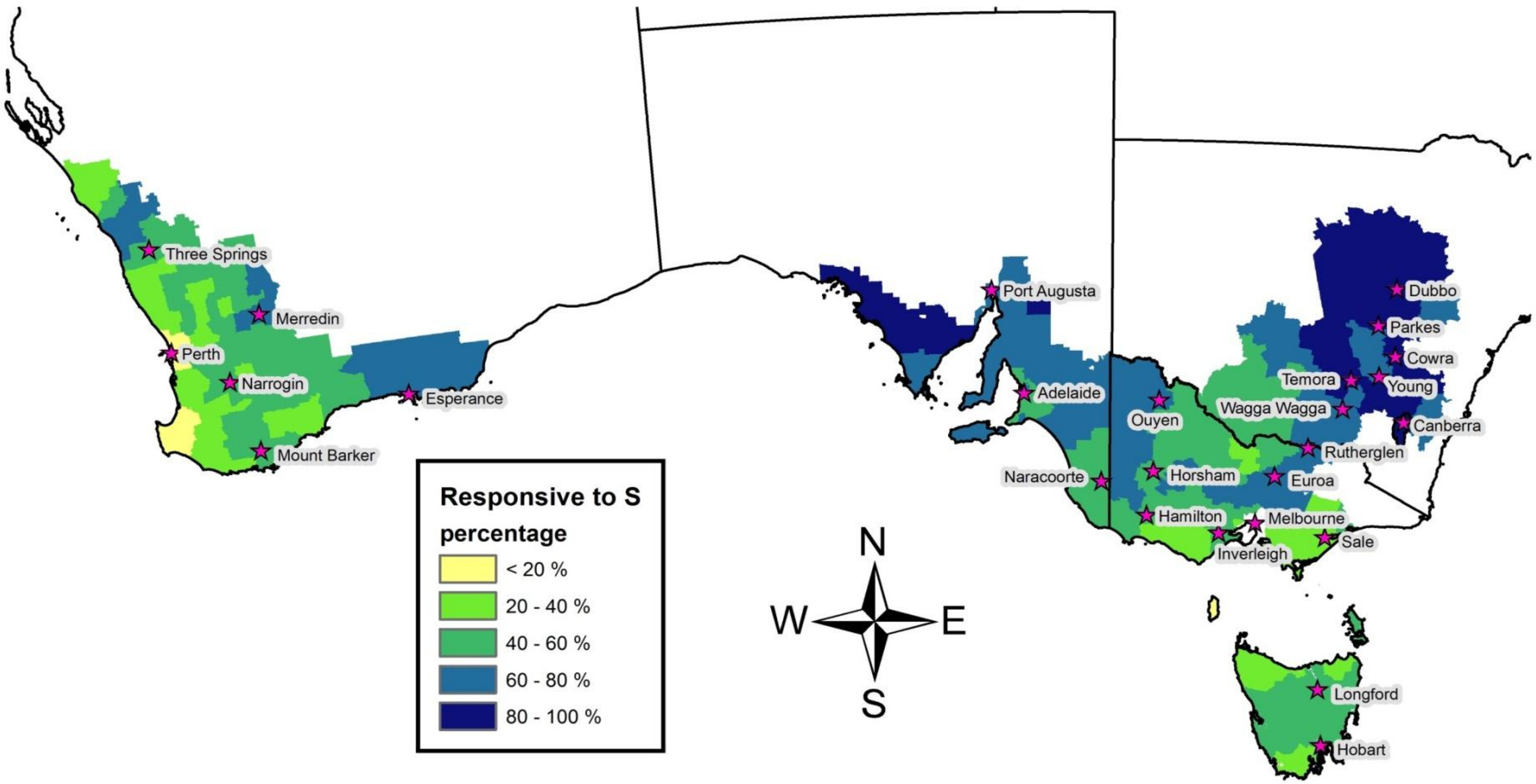


Figure 17: The bar charts show the percentage of tests in each category range per soil type based on diagnostic ranges defined in Table 5 and the spatial map shows the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') in the National Land and Water Resources Audit nutrient database

Overall, national nutrient audits in 1995/1996 and 2009/10 showed the S balance in cropped area of south-eastern Australia was neutral or positive throughout most of south-eastern Australia (Audit 2001; IPNI 2013b). Sulphur grain concentrations for wheat grown in NVT (2008 - 2009) in the HRZ (averaging 4-5 t ha^{-1}) are above the critical value of 1200 mg S kg^{-1} (Reuter *et al.* 1997b; Norton 2012) however about 40% of soils in the HRZ have low S content in the topsoil (<8 mg kg^{-1} KCl-40) (R. Norton, *pers*. *comm*.). A recent analysis of 2010 soil test data compiled from Incitec Pivot's soil test database for the HRZ of Victoria and South Australia demonstrated that about 40% of soils have low topsoil S (below 10 mg kg^{-1}) and therefore would achieve an additional crop response to additional sulphur in fertiliser (Figure 18).

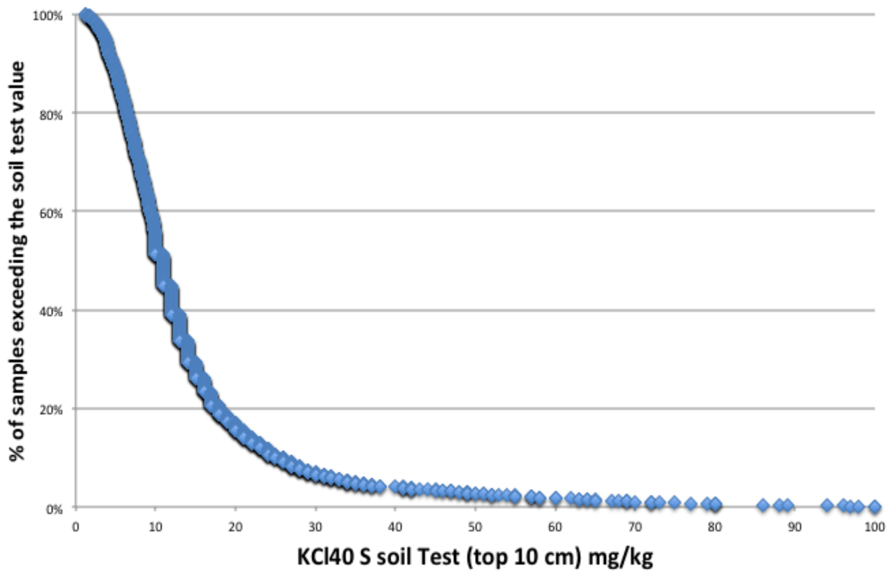
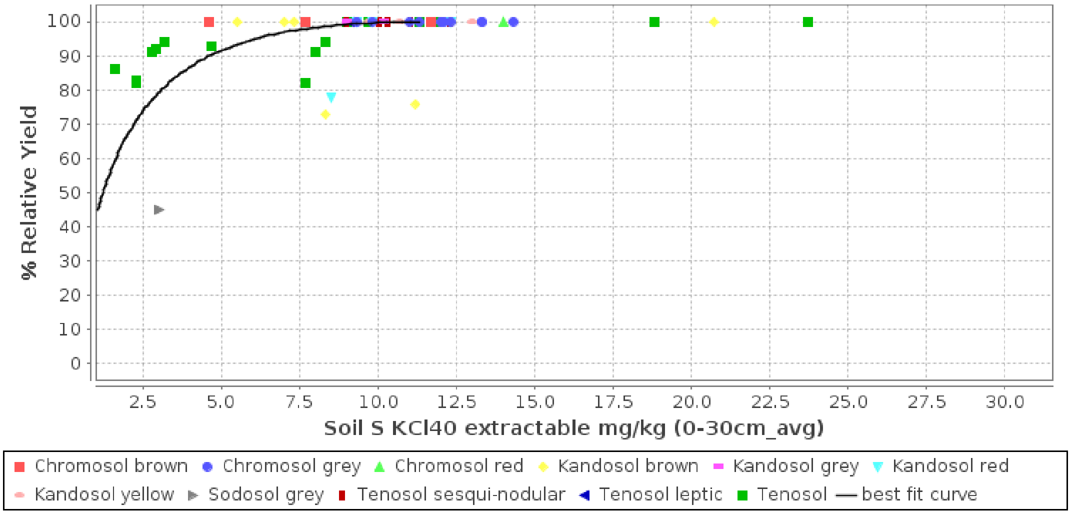


Figure 18: Compiled sulphur soil sample results (n=1,964) compiled from data sourced from Incitec Pivot soil tests 2010 for the SA and Vic HRZ (Critical value 10 mg kg^{-1}).

An analysis of data in the BFDC database for wheat grown as a winter crop under rain fed conditions in all of Australia shows that S values measured to 30 cm correlates with grain yield and 90% maximum grain yield is attained with 5 mg S kg^{-1} (Figure 19). This critical value is at the lower end of the range given by Lewis (1999) as a generic value for all crops grown throughout Australia (5-10 mg S kg^{-1}).

An analysis for canola grown in the winter under rain fed conditions indicates that 90% maximum grain yield is attained with 7 mg S kg^{-1} (Figure 20). This critical value is in the range given by Lewis (1999) as a generic value for all crops grown throughout Australia (5-10 mg S kg^{-1}). There is insufficient data in this database to produce a response curve for the whole of south-eastern Australia or any region or soil type within south-eastern Australia.



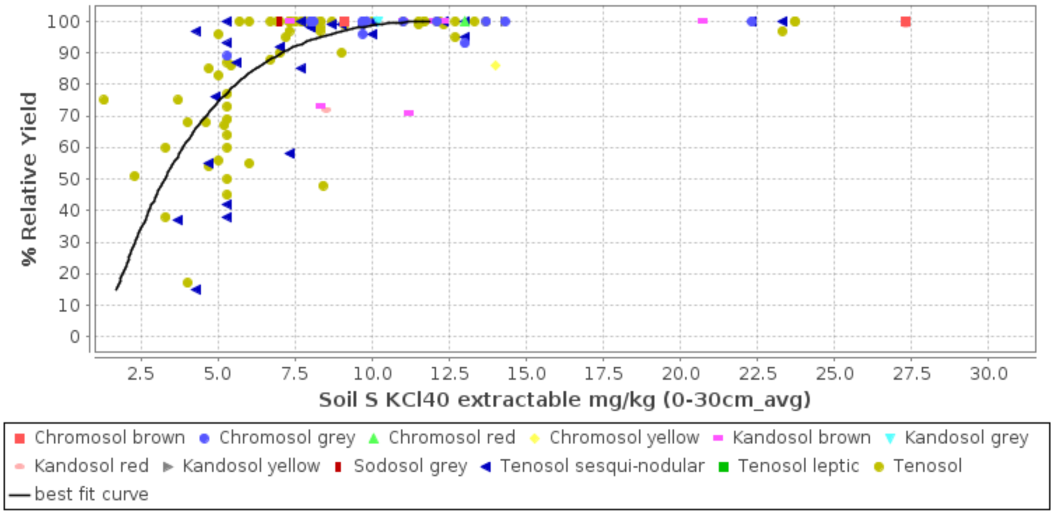
Soil test calibration:

80% Relative Yield: 3.1 (2.1 - 4.5) Correlation R: 0.63 Slope RY(50-80): 16.0 (11.0 - 21.0)

90% Relative Yield: 4.6 (3.5 - 6.1) Regression equation: $x = e^{(2.8599(arcsin(sqrt(y/100))) + -2.0436)}$

95% Relative Yield: 6.1 (4.9 - 7.5) 70% confidence limit at 90% Relative Yield: 4.6 (4.0 - 5.3)

Figure 19: Sulphur response curve for wheat using data extracted from the Better Fertiliser Decisions for Crops (BFDC) database . Data is S as measured by KCl-40 method in 0-30 cm layer for all sites in Australia under rain fed winter conditions. (http://www.bfdc.com.au/frontpage.vm)



Soil test calibration:

80% Relative Yield: 5.6 (4.9 - 6.4) Correlation R: 0.63 Slope RY(50-80): 13.0 (10.0 - 16.0)

90% Relative Yield: 7.1 (6.3 - 7.9) Regression equation: $x = e^{(1.6674(arcsin(sqrt(y/100))) + -0.12669)}$

95% Relative Yield: 8.3 (7.4 - 9.3) 70% confidence limit at 90% Relative Yield: 7.1 (6.7 - 7.5)

Figure 20: Sulphur response curve for canola using data extracted from the Better Fertiliser Decisions for Crops (BFDC) database. Data is S as measured by KCl-40 method in 0-30 cm layer for all sites in Australia under winter conditions. (http://www.bfdc.com.au/frontpage.vm)

Some extension publications make blanket recommendations to apply up to 20 kg S ha^{-1} to all canola crops to prevent S deficiency (Stanley *et al.* 1999) and 30 kg S ha^{-1} or 40 kg S ha^{-1} to crops with a history of S deficiency (Good and Glendinning 1998; GRDC 2009a). These blanket recommendations seem to be a reasonable guide for canola grown for grain in lower rainfall environments when the aim to supply sufficient S to match S removed in grain. These recommendations are considered too low for canola grown in the HRZ and perhaps explains the frequency of sulphur deficient soils in this region.

Nitrogen

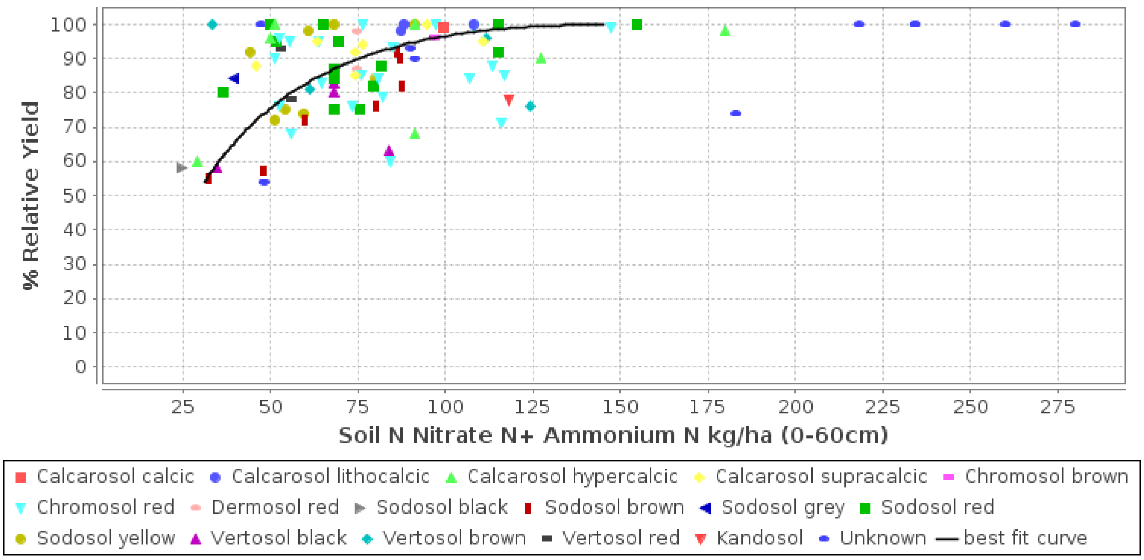
Crop production in Australia relies mainly on nutrients supplied in the form of fertilisers. However in the case of nitrogen (N), it may also be sourced from legumes. There is no need to use N fertiliser on farms where at least 40% of land is in a well manage legume-pasture phase at any one time (Angus and Peoples 2012). This general strategy of including pastures in rotation with a cropping phase was undertaken to address low soil N in the 1930–1970s (Puckridge and French 1983). During this period, wheat grain production increased with little use of N fertiliser. However, by the late 1980s, the legume content and the length of the pasture phase decreased, and the amount of N fertiliser applied to wheat was small (estimated to be only 2-3 kg ha^{-1} (McDonald 1989)). During this period, wheat productivity stagnated and grain protein content declined (Hamblin and Kyneur 1993). This compares to estimates in the 1990's which found nitrogen fertiliser application rates vary between regions with less than 10 kg N ha^{-1} applied to most of the Wimmera, Mallee, southern Victoria and Eyre Peninsula regions, 10-20 kg N ha^{-1} for remaining regions in Victoria and South Australia, and higher rates ranging from 40–200 kg N ha^{-1} in most of southern New South Wales (Audit 2001). The impact of the difference in N application rates are evident in the calculation of N balance for cropping in each State (Audit 2001) where the balance of fertiliser N imports less N exported in commodities found a:

- Negative N balance for crops in Victoria;
- Negative to neutral N balance for crops in South Australia;
- Neutral to positive N balance for crops in New South Wales.

A similar audit conducted in 2009/2010 found a similar trend of negative N balances being widespread throughout the cropping districts of Victoria, South Australia and southern New South Wales (IPNI 2013b). In recent times, the, the average N fertiliser use has increased; estimated at 43 kg ha^{-1} in 2000 (Chen *et al.* 1999; Angus and Peoples 2012).

Site-specific crop-modelling shows that applying 50 to 100 kg N ha^{-1} produces profitable improvements in grain yield in Victoria, New South Wales and South Australia in the majority of seasons with the exact optimal rate depending on the variety type, starting soil N and timing of N application (Clough *et al.* 2010). These amounts are far greater than were applied to crops in the HRZ during the 1990s (less than 10 kg N ha^{-1} (Audit 2001)) and current applications (2007-2010) are less than required to balance N budgets throughout the region (IPNI 2013b).

An analysis of the 92 N experiments in the Better Fertiliser Decisions database shows that 90% maximum grain yield is achieved in south-eastern Australia when soil mineral N is between 61-92 kg ha^{-1} (Figure 21). This critical range is only a guide with the same data sets showing a lower range of critical values for lower rainfall environments (62-75 kg N ha^{-1} at < 450 mm growing season rainfall [GSR]) and a higher and broader range for higher rainfall environments (77-120 kg N ha^{-1} for > 450 mm GSR).



Soil test calibration:

80% Relative Yield: 56.0 (44.0 - 72.0)

90% Relative Yield: 75.0 (61.0 - 92.0)

95% Relative Yield: 92.0 (74.0 - 110.0)

Correlation R: 0.43

Slope RY(50-80): 1.1 (0.59 - 1.6)

Regression equation: $x = e^{(2.092(\arcsin(\mathrm{sqrt}(y/100))) + 1.7078)}$

70% confidence limit at 90% Relative Yield: 75.0 (68.0 - 84.0)

Figure 21: Calibration curve of responsiveness of wheat to N relative to soil mineral N. Data is mineral N as measured in the 0-60 cm layer. Data sourced from the Better Fertiliser Decisions (BFDC) database for all of south-eastern Australia under rain fed, winter crop production (http://www.bfdc.com.au/frontpage.vm).

The broad range in critical N values in the HRZ, is in part due to N mineralisation that occurs during the season which is itself dependent on soil temperature and soil water content (Gill et al 1995, Strong and Mason 1999). In low rainfall environments of New South Wales, the combination of total soil N, mineral N and potentially mineralisable N accounts for up to 94% of variation in wheat grain yield when considered with growing season rainfall (Xu and Elliott 1993). A similar analysis for the HRZ would be helpful in understanding the importance of in-season mineralisation to wheat and canola production but is not in the literature. Responsiveness of wheat to N is further complicated by there being a broad range in N use efficiency (38% to 88%) depending on timing and rate of application (Angus and Fischer 1991, Chen et al 2008, Ladd and Amato 1986). Nitrogen loss through leaching under intense rainfall and N_2O emissions under water logged conditions can also be high in the HRZ thus reducing N use efficiency (Harris et al 2013, Ridley et al 2001).

In the HRZ, the BFDC only provides a broad range of critical values for soil N. This is due to too few experiments, a lack of knowledge on the contribution of in-season N mineralisation to the N supply and limited quantified information about N loss during the season through leaching and gas emissions. This lack of information hampers our ability to accurately predict N fertiliser requirements for specific crops in any particular season. Whilst crop modelling can help estimate N requirements in the HRZ for a range of starting soil N and variety types, the Yield Prophet model that is used to predict N requirements for individual crops tends to underestimate high wheat grain yields (> 4 t ha^{-1}), especially in New South Wales (Hochman et al 2009).

Given canola needs more N than wheat, adding canola to a wheat-based cropping system increases the need for N fertiliser and/or leguminous pastures (Holmes 1980; GRDC 2009b). Early extension publications give blanket recommendations for rates of N fertiliser to be used on canola that varies with prior crop and rainfall environment (Hocking *et al.* 1999; Stanley *et al.* 1999). Blanket recommendations for south-eastern Australia range from 0-40 kg N ha^{-1} after a pasture to 50-100 kg N ha^{-1} after a cereal in higher rainfall environments (Hocking *et al.* 1999). More recent advice about the amount of N needed is based on target yields and environment (GRDC 2009b).

Acidity

The yield penalty in the soils where the pH in $CaCl_2$ (pH_{ca}) is less than 4.7 is of the order of 20-100% (depending on variety) with wheat (Coventry 1992; Tang et al. 2001) and even more with barley (Coventry 1992). Low soil pH can also result in elevated concentrations of soluble aluminium which inhibits plant growth and reduces plant availability of phosphorus through increased P sorption (Haynes and Mokolobate 2001).

By using all pH_{ca} soils tests which reported a soil texture in the NLWRA database (n=240,645) a spatial map of the percentage of soil tests which will respond to additional lime was determined (Figure 23). This potential to respond was based on the diagnostic ranges for acidity (Table 6) and indicate that most regions in HRZ were found to have a considerable number of soils which will respond to lime application.

Table 6: pH_{ca} diagnostic range used for soil tests (From National Land and Water Resources Audit)

Low	Marginal	Adequate	High
<4.4	4.4-5.0	5.0-6.5	>6.5

Soils in the HRZ of New South Wales and Victoria tend to be acidic (Wilson *et al.* 2009) with about 50% of soils in the Victorian HRZ having a pH_{Ca} less than 5 (R. Norton *pers. comm*.). This is consistent with an analysis of 2010 soil test data from Incitec Pivot's soil test database for the HRZ of Victoria and South Australia, which found that about half the soils have pH_{ca} <5.0 and would be responsive to lime application (Figure 22).

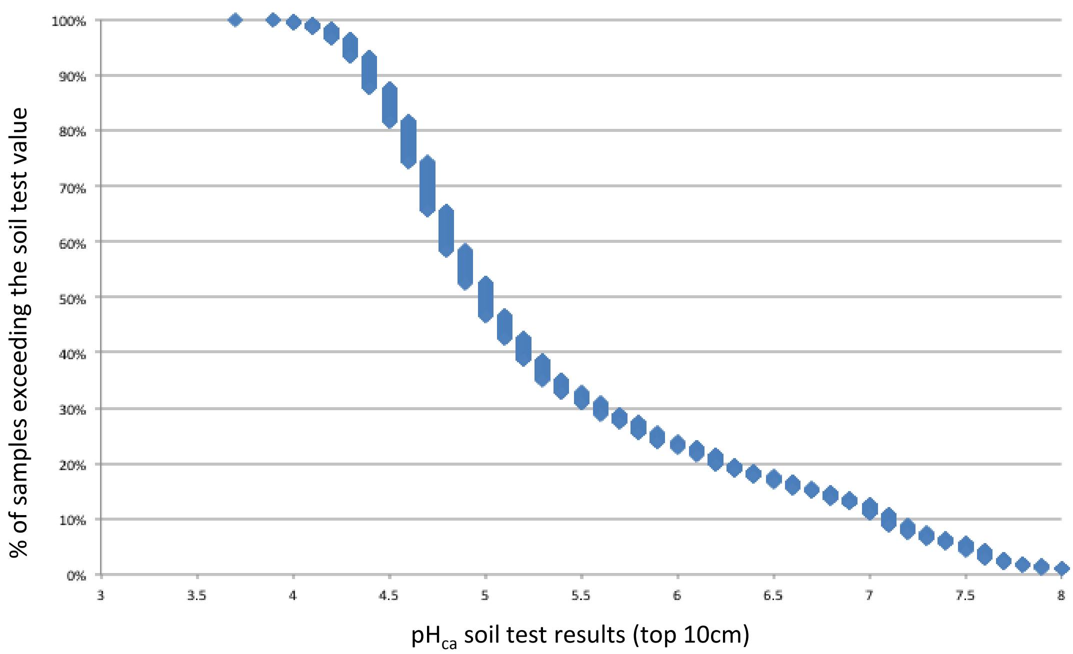
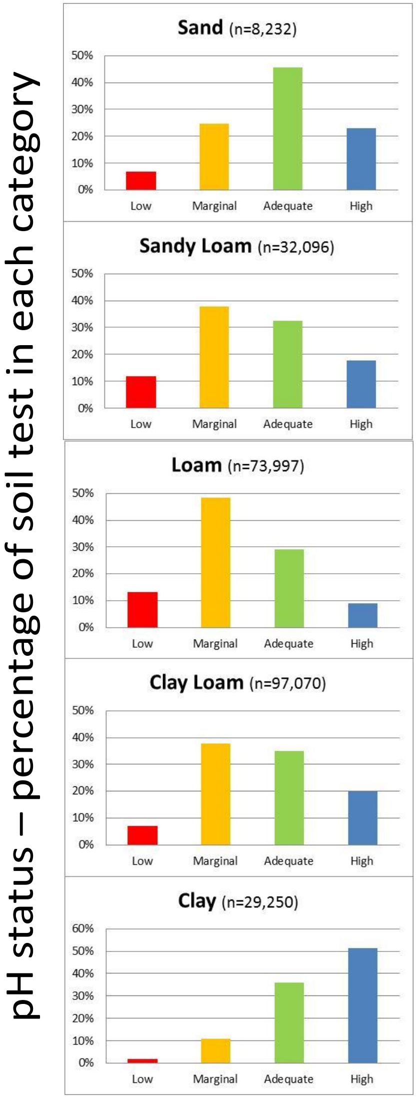


Figure 22: Compiled acidity (pH_{ca}) soil sample results compiled from data sourced from Incitec Pivot soil tests 2010 for the SA and Vic HRZ.



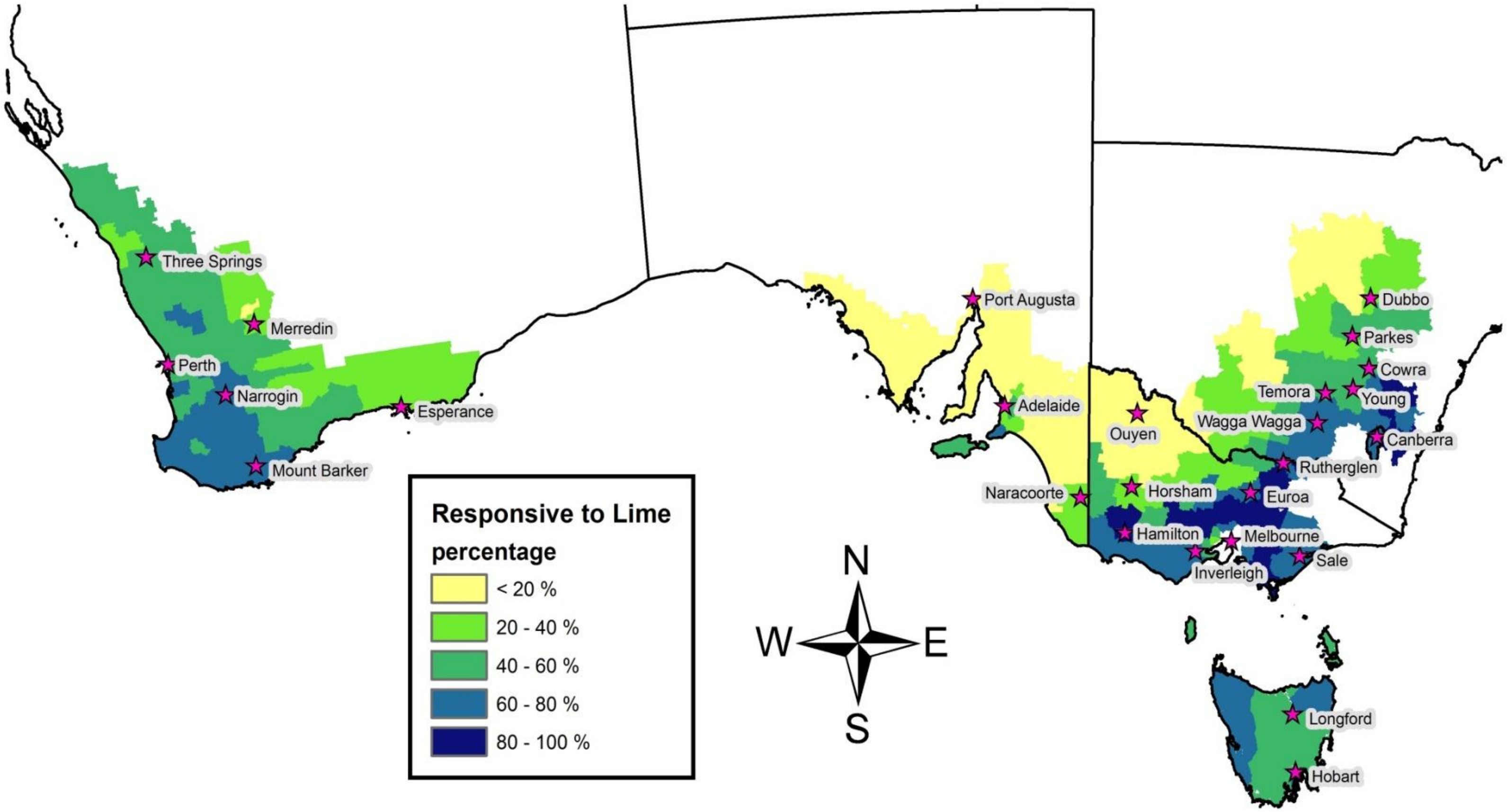


Figure 23: The bar charts show the percentage of tests in each category range per soil type based on diagnostic ranges defined in Table 6 and the spatial map shows the number of soil tests in each Statistical Local Area that were found to be potentially responsive ('Low' and 'Marginal') in the National Land and Water Resources Audit nutrient database

Micronutrients

Micronutrient soil test data compiled from Incitec Pivot's soil test database (2010) for the HRZ of Victoria and South Australia found that in the majority of soil tests micronutrients were found not to be deficient (Figure 24). Although in other regions of the HRZ there are risks of micronutrient deficiencies (Table 7).

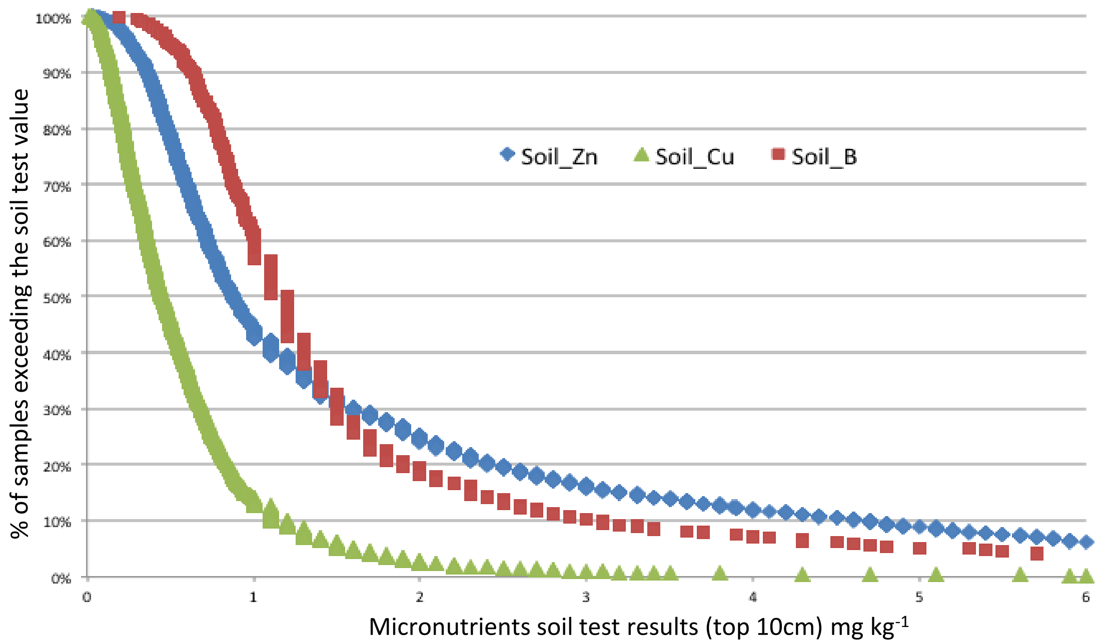


Figure 24: Compiled Cu, Zn and B soil sample results (n=>1,500) compiled from data sourced from Incitec Pivot soil tests 2010 for the SA and Vic HRZ. Critical value <0.3 for Cu, <1.0 for Zn and <1.0 for B.

Copper

The calcareous sands of south-eastern Australian (commonly known as 90-mile Plain) was one of the first regions in the world where a deficiency of Cu in soil was recognised as reducing growth and yield of wheat, other cereals and permanent pastures (Riceman *et al.* 1940). A broader view of the diagnosis of micronutrient deficiencies in wheat and other crops shows that other regions with Cu-deficient soils includes the coastal areas of southern Australia (Donald and Prescott 1975). Individual field experiments have demonstrated inconsistent and isolated grain yield responses to copper on duplex acid soils in the southern Wimmera (Donald *et al.* 1987; Flynn and Gardner 1987; Gardner and McDonald 1988) but not on other soil types in the Wimmera. Field observations and field experiments compliment soil testing in Victoria showing about 30% of soils in the Western Districts are deficient in Cu (Norton 2012) and about 50% of soils in the HRZ have DTPA-Cu less that 0.5 mg Cu kg^{-1} (R. Norton, *pers*. *comm*.).

Plant testing (youngest emerged blade) is promoted as the preferred technique for diagnosing Cu-deficiency (BCG 2009) and only a limited number of Australian soil types are calibrated for Cu-deficiency in wheat. Thus interpretation of Cu values for most soil types, including most of the HRZ of south-eastern Australia, relies on extrapolation. Critical Cu values (by DTPA extraction) for wheat are 0.2 mg kg^{-1} on the Eyre Peninsula, and gravel and duplex sandy soils in Western Australia (Brennan and Best 1999).

Zinc

Zn deficiency in wheat was initially recognised in Australia in the 1940's on the calcareous sandy soils of Western Australia (Riley *et al* 1992). Zinc deficiency in wheat is also evident in south-eastern Australia with 20% of wheat crops analysed by the South Australian Soil and Plant Analysis Service between 1995 and 1999 showing at least marginal deficiency in Zn (McDonald *et al* 2001). A similar survey of Victorian soils submitted to a commercial soil testing laboratory in 2011 shows Zn deficiency (< 0.5 mg kg^{-1}) present in 37% of soils in the Western District (Norton 2012) and about 20% of soils have DTPA-Zn less that 0.5 mg Zn kg^{-1} (R. Norton, *pers*. *comm*.). Critical extractable Zn values for wheat vary with soil type (Armour and Brennan 1999) and not all soil types have been calibrated for the extraction. This limits interpretation of test results with some soils being unresponsive to Zn although they are deemed to be Zn deficient (Oliver *et al* 1997). Zn values (by DPTA extraction) for wheat have been determined as 0.12-0.27 mg kg^{-1} for sandy soils in Western Australia and 0.8 mg kg^{-1} for red brown earths, clays and loams on the Eyre Peninsula and Mallee of South Australia (Armour and Brennan 1999).

Table 7: Soil test values (0-10 cm) by region as taken from the NVT soil test database 2008-2012. Values given are the means and standard errors for each analyte. Low, medium and high risk are indicated by green, yellow and red cell shading. Font colour indicates low (green), medium (orange) or high (red) risk of micronutrient deficiency from the data (IPNI 2013b).

State	Region	pH ($CaCl_2$)	HWS B (mg kg^{-1})	DTPA Cu (mg kg^{-1})	DTPA Mn (mg kg^{-1})	DTPA Zn (mg kg^{-1})
NSW	N/E	7.0±0.1	0.9±2.3	1.7±0.1	41.2±5.5	1.0±0.4
	N/W	7.0±0.1	1.0±2.5	1.6±0.1	20.0±4.9	0.4±0.3
	S/E	5.3±0.1	0.7±1.1	0.7±0.1	40.7±4.9	2.3±0.3
	S/W	5.7±0.1	2.1±5.6	1.0±0.1	28.3±6.9	2.7±0.5
Qld	CQ	7.5±0.2	0.7±1.2	1.3±0.2	61.5±11.1	0.7±0.7
	SEQ	7.1±0.3	0.5±1.6	1.6±0.3	25.3±15.7	1.4±1.1
	SWQ	7.4±0.2	0.8±1.0	1.0±0.2	11.6±9.6	0.7±0.7
SA	Lower EP	7.1±0.1	5.6±0.8	1.9±1.0	14.8±54.2	3.9±3.8
	Mid North	6.9±0.1	2.7±0.7	0.5±1.0	1.1±54.3	0.3±3.8
	Murray Mallee	7.4±0.2	2.3±1.3	-	-	-
	South East	7.1±0.1	3.1±0.6	0.8±0.1	1.7±7.0	0.9±0.5
	Upper EP	7.7±0.1	5.1±0.8	-	-	-
	Yorke P	7.4±0.1	3.7±0.7	-	-	-
Vic	Mallee	7.4±0.2	5.6±1.0	0.4±0.6	4.6±31.3	0.7±2.2
	North Central	5.8±0.2	3.7±1.0	1.4±1.0	47.8±9.7	0.7±0.7
	North East	5.2±0.1	2.1±0.9	0.6±0.2	34.4±8.7	0.6±0.6
	South West	5.4±0.3	3.4±1.7	0.5±0.3	21.8±16.3	0.5±1.4
	Wimmera	7.7±0.1	8.9±0.8	0.4±0.2	4.8±8.7	0.6±0.6
WA	Agzone1	5.3±0.3	0.3±1.9	0.4±0.3	8.8±18.1	0.7±1.3
	Agzone2	4.9±0.2	0.8±3.2	0.8±0.3	11.9±18.1	0.7±1.0
	Agzone3	5.1±0.2	0.5±1.5	0.4±0.2	3.7±14.5	0.4±1.0
	Agzone4	5.2±0.4	0.3±5.6	0.7±0.5	44.8±27.1	0.8±01.9
	Agzone5	6.0±0.2	11.6±1.6	0.5±0.3	3.5±18.1	1.2±1.3
	Agzone6	5.4±0.3	0.7±2.5	0.6±0.6	5.4±31.3	1.4±2.1
Means	All zones	6.3±1.3	3.5±13.3	1.1±1.0	24±43	1.0±2.9
Critical Value (approx.)			0.5	0.2	5	0.2

Situation analysis - Input costs and yield targets in the HRZ

Nutrition as a constraint to maximising grain yields

Crop nutrient requirements are based on having a target or expected grain yield and working out how much of a nutrient the crop needs to achieve that yield. The general principal is to supply enough of a nutrient to meet the needs of the crop in the current year (GRDC 2010). The nutrient may be sourced from the soil where there is adequate supply or from fertiliser applied at a time that suits crop demand. For nitrogen, the source of N is an additional and important part of the decision-making process as N is sourced from the soil at sowing (i.e. initial N), fertiliser N and N estimated to become available through net mineralisation during the growing season (McDonald 1989; DPI 2005).

Estimating the nutrient requirement for a crop of a specific target yield is a simple process since there is information available detailing the concentration of each nutrient contained in wheat and canola whole plants and concentrated in grain (Schultz and French 1976; Reuter *et al.* 1997b; Norton 2012). These concentrations are based on a range of varieties within a crop species and although not necessarily derived in the HRZ have a universal application. Estimating nutrient supply from the soil to a crop is a more complex process that requires local information detailing the amount of nutrient that is in the soil and the crop's response to the presence of that nutrient.

With the introduction of superior varieties with high yield potential to the HRZ, new management practices and greater inputs will be required for the potential to be realised. Management of high input systems can be complex 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. This amount of fertiliser requires considerable up-front costs and are 3 to 4 times greater than those currently applied on-farm. Additionally, due to a greater number of rain days during the growing season in the HRZ compared to other cropping regions, the frequency of application for fungicides and possibly plant growth regulators is more.

Balancing all inputs including fertility is essential for optimizing yields, increasing profits, and improving the efficiency of fertiliser applications. Nitrogen (N) may be the most common limiting nutrient, however, without balanced nutrition, fertiliser N applications may be less efficient, and part of the fertiliser investment is wasted (Johnson et al. 1997). Inadequate supply of one nutrient to a crop restricts crop growth and grain yield, and can reduce uptake and use of other nutrients that are adequately supplied (Grant *et al.* 2001; Armstrong *et al.* 2009). This interaction not only applies to N but is also well documented for P and S (Archer 1974; Dunbabin *et al.* 2009). Weaver and Wong (2011) found that 63% to 89% of the soil samples exceeded critical values where little yield improvement would be achieved by applying additional P. Additionally, over 50% of the samples had indications of more important constraints (soil acidity, potassium and sulphur deficiency) to yield.

There is a perceived risk by growers and advisors that they will not achieve a return on investment with the rates of fertiliser required to achieve the full yield potential in the HRZ. To address this risk there needs to be greater understanding of the economics of crop response based on each additional unit of input applied. Additionally, climate variability and other factors can cause crop failure in the year of application, hence there is a need to understand to what degree does an investment in nutrients flow on in subsequent years to allow a return on investment?

Variable inputs used in general cereal and oilseed cropping systems include nutrients (N, P, K, S + micronutrients), herbicides, pesticides, fungicides and soil ameliorants (e.g. lime, gypsum). As rainfall and yield potential increase, so too do the variable costs. Inputs costs for the HRZ are greater than the Mallee but often less than the Wimmera, with median variable costs in the low rainfall region for wheat at \$220 ha^{-1} (range \$140-\$300) and for canola at \$280 ha^{-1} ((range \$220-400). In the Wimmera the median cost for wheat is \$420 ha^{-1} (range \$250-\$550) and for canola is \$550 ha^{-1} (range \$400-\$800) (Chris Sounness *pers*. *comm*.). Survey of advisers in the HRZ shows the median cost for wheat is \$330 ha^{-1} (range \$310-\$450) and for canola \$400 ha^{-1} (range \$320- \$480). These costs are similar to the cost for low, medium and high rainfall cropping in South Australia (Rural Solutions 2012).

Of these input costs, fertiliser is the largest single variable cost for grain producers, and is 15-20% of all cash costs, or 20-25% of variable costs (Rural Solutions 2012; IPNI 2013a).

The cost of inputs to HRZ cropping enterprises

The Livestock Farm Monitor research program measured a range of all actual inputs and production response on 110 farms in the HRZ of Gippsland, North East and South West Victoria between the years of 2000-2011. Drawing on this data along with a compilation of additional data gathered from interviewing cropping consultants allowed a tabulation of the average variable costs of conducting canola (Table 8) and wheat (Table 9) enterprises. This data demonstrates surprisingly that the amount of fertiliser inputs applied on average is about the same as what is applied in the Wimmera, suggesting that the HRZ is not applying adequate fertiliser to match their yield potential. A breakdown of this data on an annual basis shows that fertiliser is the highest single variable input cost to crop production (Figures 25 and 26).

Table 8: Typical variable costs, yields and returns for canola in the different rainfall zones. Variable costs include seed, fertiliser, chemical sprays, machinery operating costs (fuel, repairs and maintenance), contractors (spraying and harvest), labour (casual), insurance, freight, interest (overdraft). HRZ Livestock = major enterprise is livestock with 4% cropping - data from Livestock Farm Monitor Report 2000-2011 and includes Gippsland, NE Vic and SW Vic. 'HRZ Croppers' is where cropping is 30% + of the enterprise mix – data from cropping consultants.

CANOLA	Low Rainfall Zone (Mallee)	Medium Rainfall Zone (Wimmera)	High Rainfall Zone (Livestock)	High Rainfall Zone (Croppers)
Herbicides	40	62	44 (28-66)	40-80
Pesticides	0.5			40
Fungicides	6	5		6
PGR				
Fertiliser	90	110	83 (61-124)	120 (60-220)
Seed	13	24	24 (16-41)	24
Soil ameliorants			8 (0-20)	80
Total variable costs	220	427	280	330
Yields (t ha^{-1})	2.6	3.5	3.3	4.0
Gross Margin ($ ha^{-1})	$162	413	488	470

Table 9: Typical variable costs, yields and returns for wheat in the different rainfall zones. Variable costs include seed, fertiliser, chemical sprays, machinery operating costs (fuel, repairs and maintenance), contractors (spraying and harvest), labour (casual), insurance, freight, interest (overdraft). HRZ Livestock = major enterprise is livestock with 4% cropping - data from Livestock Farm Monitor Report 2000-2011 and includes Gippsland, NE Vic and SW Vic. 'HRZ Croppers' is where cropping is 30% + of the enterprise mix – data from cropping consultants

WHEAT	Low Rainfall Zone (Mallee)	Medium Rainfall Zone (Wimmera)	High Rainfall Zone (Livestock LFMP)	High Rainfall Zone (Croppers)
Herbicides	63	115	63 (41-86)	85
Pesticides	5	4		60
Fungicides	0	3		
PGR				
Fertiliser	87	146	106 (67-167)	150 (60-220)
Seed	23	68	33 (24-56)	33
Soil ameliorants		60	29 (8-51)	80
Total variable costs	284	663	374	408
Yields (t ha^{-1})	1.3	2.1	1.7	2.5
Gross Margin ($ ha^{-1})	101	450	419	842

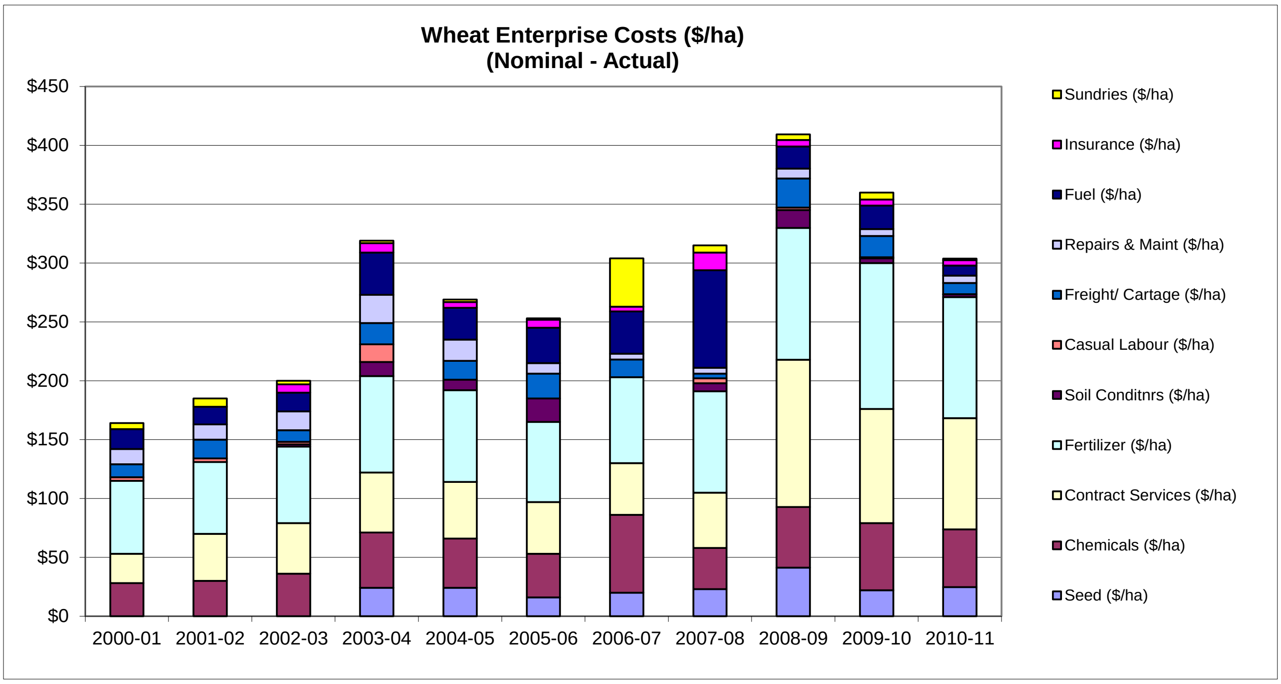


Figure 25: The cumulative variable input costs for Victorian wheat crops (DEPI 2013)

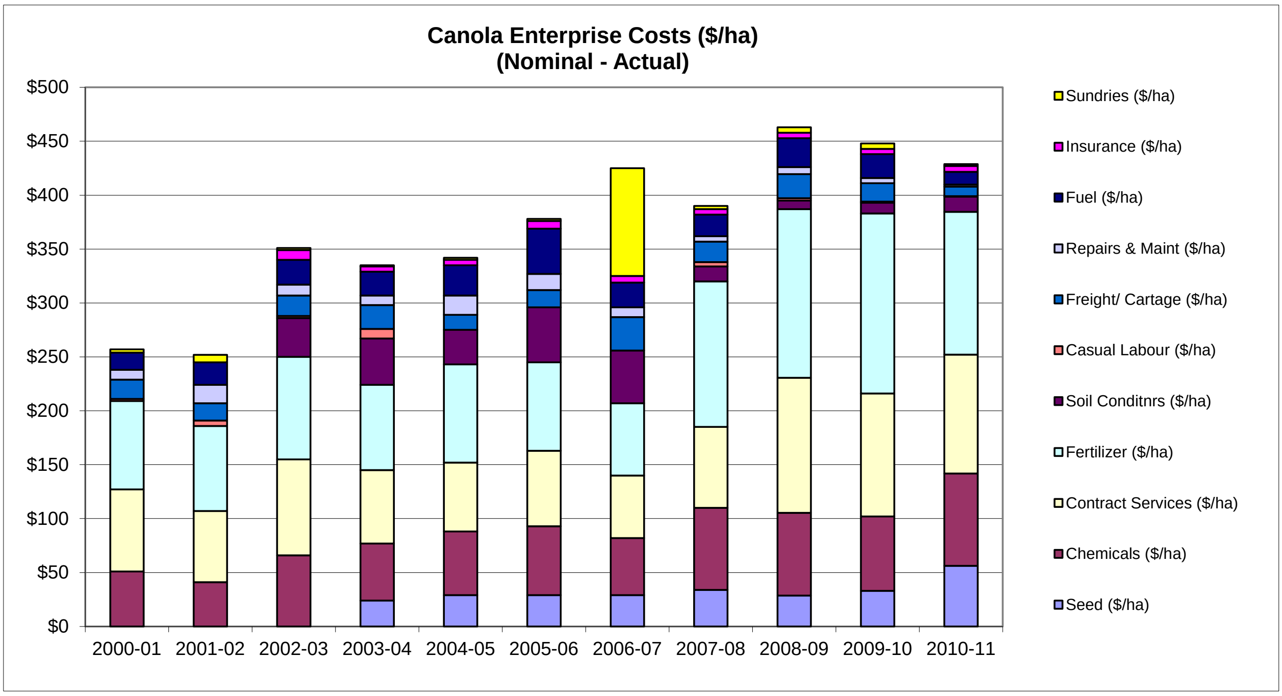


Figure 26: The cumulative variable input costs for Victorian canola crops (DEPI 2013)

Nutrient removal in grain

Soil fertility will eventually fall if the nutrients (phosphorus, nitrogen, zinc, etc.) removed as grain from the paddock are not replaced, impacting on crop yields. A balance sheet approach to fertilizer inputs is a good starting point in considering the amount of fertilizer to apply to your crop to match the higher expected yield, particularly for the major nutrients, phosphorus, potassium and sulphur.

The nutrients removed by one tonne of grain by the various crops are shown in Table 10. Actual values may vary by 30% or sometimes more, due to the differences in soil fertility, varieties and seasons (Table 11). Table 10 is a guide of the minimum amount of nutrient that needs to be replaced per tonne of crop removed. Higher quantities may be needed to build up soil fertility. Soil types do vary in their nutrient reserves. For example, most black and red soils have sufficient reserves of potassium to grow many crops. However, the light, white sandy soils which, on soil test, have less than 50ppm (Bicarb test) of potassium will respond to applications of potassium fertilizer. Other soils may have substantial nutrient reserves which vary in availability during the growing season or are unavailable due to the soil's pH.

Table 10: Nutrients removed by one tonne of annual crop: (data from www.grdc.com.au/uploads/documents/Nutrition.pdf for all crops except canola which was sourced from summitfertz.com.au/NutrientRemoval.html)

Crop	Kilograms per tonne grain						Grams per tonne grain		
	N	P	K	S	Ca	Mg	Cu	Zn	Mn
Wheat	23	3.0	4	1.5	0.4	1.2	5	20	40
Barley	20	2.7	5	1.5	0.3	1.1	3	14	11
Oats	17	3.0	5	1.6	0.5	1.1	3	17	40
Canola	40	6.5	9.2	5.0	4.1	4.0	4	40	40
Peas	38	3.4	9	1.8	0.9	1.3	5	35	14
Faba beans	41	4.0	10	1.5	1.3	1.2	10	28	30

Table 11: Wheat grain micronutrient concentration and standard errors arranged by agroecological zones.

Agroecological Zone	B mg kg^{-1}	se* of B	Cu mg kg^{-1}	se* of Cu	Mn mg kg^{-1}	se* of Mn	Zn mg kg^{-1}	se* of Zn
NSWNEQldSE	1.1	0.3	4.7	0.8	46.3	8.2	24.0	5.6
NSWNWQldSW	1.2	0.3	4.4	0.9	53.8	11.4	20.4	4.2
QldCentral	1.0	0.2	4.9	0.9	42.5	3.7	28.2	6.6
NSWVicSlopes	1.2	0.5	3.6	0.9	44.4	8.1	16.0	4.2
NSWCentral	1.5	0.5	3.2	0.9	46.1	9.1	16.9	3.1
SAMidnorthLYP	2.1	1.0	3.7	0.9	35.2	10.2	20.4	5.0
SAVicMallee	2.1	0.9	3.7	0.8	35.2	8.7	17.0	4.5
SAVicWimmera	1.9	1.2	3.5	1.1	30.4	10.2	20.0	5.6
VicHRZ	1.2	0.5	4.0	0.8	53.3	9.6	18.2	3.4
WACentral	1.1	0.5	3.2	1.1	39.3	13.1	22.4	4.8
WAEastern	1.4	0.7	3.4	1.7	50.5	24.1	22.8	5.3
WANorthern	0.9	0.2	3.2	1.3	54.9	14.2	24.8	6.3
WASandplain	1.0	0.4	1.9	1.2	40.1	14.4	19.0	2.1
Grand Total	**1.4**	**0.7**	**3.8**	**1.1**	**42.7**	**12.2**	**20.0**	**5.7**
Approx Critical Value	**1.0**		**1.5**		**10**		**15**	

* se = standard error of the mean.

Fertiliser expenditure in the Australian grains industry

The data in Table 12 is taken from the 2011 ABARES farm input surveys on farm costs for grain and mixed farming properties in each of the agro-ecological zones (IPNI 2013a). The years surveyed were 2006-2007, 2007-2008 and 2008-2009, and the results reported are the average for those three years. Mean yields over these periods are lower than the long term average for Australia due to drought with annual wheat production of 10.8 Mt (2006-2007), 13.6 Mt (2007-2008), 21.4 Mt (2008-2009). In subsequent years wheat production totalled 21.8 Mt (2009-2010), 27.4 Mt (2010-11) and 29.9 Mt (2011-2012). Production for the current 2012-2013 crop season is forecast at 22.0 Mt. The average fertiliser cost of high rainfall cropping farms in the Victoria HRZ is $68.70 per ha. This level of spending of fertiliser is very similar to the spending on fertiliser on the Livestock Farm Monitor farms between the years 2000 to 2006; however since 2007 the fertiliser applications on the Monitor farms has increased and for canola has risen to double that of earlier applications (Figure 27).

Table 12: **The amount spent on fertilisers as a proportion of variable costs on Australian grain farms.**

Region	Specialist Grain Farms $ ha^{-1}				Mixed Farms $ ha^{-1}		
	Fertiliser	*Crop Costs	% Fert	$/cropped ha**	Fertiliser	*Crop Costs	% Fert
Central NSW	15.3	93	16%	56	6.8	53	13%
NSW & Vic Slopes	40.4	178	23%	66	20.1	121	17%
Vic HRZ & Tas	68.7	357	19%	129	35.5	191	19%
SA & Vic Wimmera	41.1	219	37%	62	30.3	190	16%
SA & Vic Mallee	24.9	111	22%	44	17.3	86	20%
SA Mid North,	47.2	231	20%	84	21.6	121	18%
WA Sandplain	73.7	275	27%	122	53.3	170	31%
WA Northern	21.9	76	29%	66	22.1	81	27%
WA Eastern	21.3	84	25%	42	34.2	114	30%
WA Central	49.3	190	26%	89	41.5	155	27%
North west NSW/SW Qld	4.4	110	4%	13	1.4	43	3%
North east NSW/SE Qld	31.4	267	12%	60	9.3	107	9%
Central Queensland	14.4	246	6%	26	2.4	55	4%

*** Crop costs were derived from the total cash cost, less administration, livestock purchases, fodder, shearing and interest.** $/cropped ha for specialist grain farms assumes that all the fertiliser is applied to the cropping areas.**

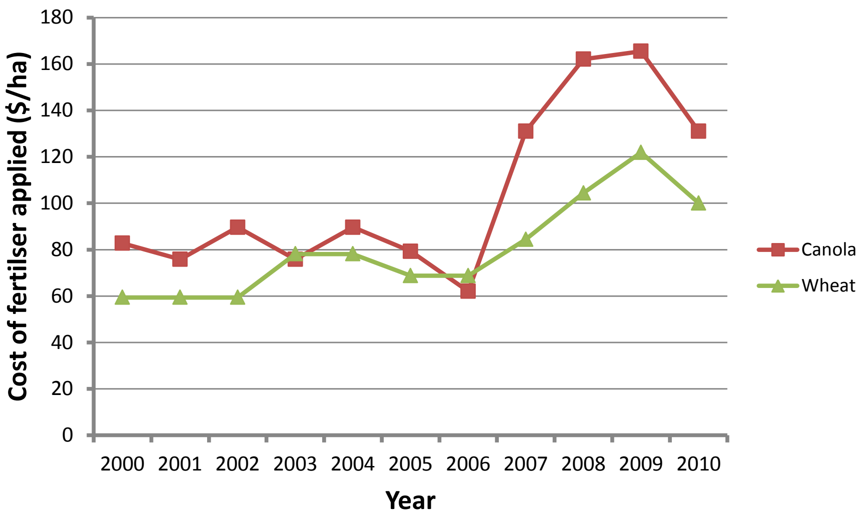


Figure 27: Annual cost of fertiliser application ($ha^{-1}) to canola and wheat on Livestock Monitor Farms

The Fertiliser Industry Federation of Australia (FIFA) maintains a database of sales of the various fertiliser products based on member data. In addition, ABS conducted a major survey in 2007-08 investigating farm usage of various fertilisers (Ryan (2010) . There is no direct concordance between the two series in terms of product classifications and many of the major products can be relatively easily cross-classified. There are major discrepancies between the two data sources. Details of these discrepancies are presented in Table 13 along with the percentage differences between the claimed usage (ABS data) and the actual sales (FIFA data) of the various fertiliser products. The overall usage of fertilisers is similar between the two data sources, for example there is only a 2.3% divergence for total phosphatic fertiliser use. However, at individual product level these divergences can be quite large.

Table 13: Fertiliser use sales 2007-08 from the Fertiliser Industry Federation of Australia and claimed usage by the ABS Agricultural Census (Ryan 2010)

Fertiliser	ABS	FIFA	Percentage Difference
Urea – tonnes applied	816,232	1,042,980	22
Ammonium sulphate – tonnes applied	166,176	263,616	37
Single superphosphate – tonnes applied	866,199	1,031,937	16
Double or triple superphosphate – tonnes applied	217,868	78,521	177
Muriate or sulphate of potash – tonnes applied	168,809	259,683	35
Ammonium phosphates – tonnes applied	875,231	1,117,114	22
Other fertilisers – tonnes applied	248,610		
Total fertiliser use – tonnes applied	4,336,082	3,868,963	12

Table 14: The area fertilised, the average rate of Nitrogen (N), Phosphorus (P) and Potassium (K) applied within high rainfall zone Statistical Local Areas (SLA) in 2001. Source ABS AgStats.

Vic HRZ SLAs	Area fertilised (ha)	N rate kg ha^{-1}	P rate kg ha^{-1}	K rate kg ha^{-1}
Ballarat - Inner North	3,339	3.4	12	6.6
Ballarat - North	16,988	9.9	16	2.2
C. Goldfields - Bal	38,397	14.3	14.1	0.4
Campaspe - Kyabram	53,136	27.8	27.7	2.3
Campaspe - South	51,815	20.8	19.7	0.8
Corangamite - North	157,876	11	15.7	7.7
Corio - Inner	1,223	5.8	15.7	0.4
Glenelg - Heywood	115,859	8.1	15.1	8.2
Golden Plains -	35,537	7.1	19	4
Golden Plains -	59,480	11.1	21.2	1.4
Gr. Shepparton - Pt A	16,282	22.8	19.2	4.1
Gr. Shepparton - Pt B	58,219	25.3	26.2	1.8
Hepburn - West	19,731	13.5	19.4	4.7
Mount Alexander - Bal	24,603	16.9	14.5	0.7
Moyne - North-East	117,506	8.8	15.2	3.4
Moyne - North-West	164,419	10.4	15.3	6
Moyne - South	126,725	17.2	15.5	11.9
Pyrenees - North	48,833	10.9	13.4	0.5
Pyrenees - South	61,778	6.5	13.3	0.7
South Barwon - Inner	3,542	13.1	11	17.8
Strathbogie	86,370	10.7	20.6	0.7
Surf Coast - East	14,546	7.6	14.7	5.6
Total	**1,276,204**	**12.8**	**17.1**	**4.8**

Tools for assessing nutrient input requirements

A review of literature into crop nutrition in the HRZ shows that few tools for estimating nutrient requirements have been developed specifically for the HRZ of south-eastern Australia. Only N fertiliser management for wheat and barley has been developed specifically for crops grown in the HRZ (Clough *et al.* 2010). Data sources for other nutrients are generic or are an extrapolation from lower rainfall environments and regions dominated by other soil types (GRDC 2011, GRDC 2012). These tools tend to be based on the concept of setting a target grain yield and fertilising the crop so nutrient removal in the grain is balanced by nutrient inputs for the major nutrients (N, P, K, S) and to mitigate immediate nutrient deficiencies for minor nutrients (Cu, Zn) (GRDC 2008, 2011). Available nutrients are estimated using a combination of soil test data, paddock records and crop testing. Making fertiliser decision requirements for the HRZ using more generalised information determined for regions where water is the main limiting factor and average yields are lower may lead growers to underestimate fertiliser requirements and not adequately account for removal of nutrients with grain.

Actual tools that farmers use to help make decisions about fertiliser are not always confined to formal information (Table 15). As is common in the whole grains industry, consultants have an important role in determining the amount of fertiliser applied. Additionally, the decision on the amount of fertiliser applied in a year by a landholder is often based on the cost of fertiliser. This is in isolation to the close historical link between the cost of fertiliser and price received for grain i.e. the cost price ratio (Jon Midwood (CEO SFS) *pers*. *comm*.). Estimating achievable yield and predicting likely returns based on actual inputs is needed to allow landholders to understand the financial implications of their decisions. The provision of simple tools which emphasise the economic potential of a crop through different inputs should enable better fertiliser management in the field.

Table 15: Farmer decision process around fertilisers use from (n = 140,704) (Ryan 2010)

Activity	Proportion of farms (%)
Soil tests	24.8
Previous paddocks yields	19.2
Standard annual rate	18.3
Consultant's recommendations	22.2
Used as much as could afford	21.7
Dependant on seasonal conditions	21.7
Leaf or stem sampling	7.5
Other/none reported	0.6

Currently many advisers are relatively new to cropping in the HRZ and have varying levels of knowledge and support in making recommendations. Often advisers do not feel adequately equipped to confidently assess crop demands and limitations, predict yield potential or the risks associated with high input systems in a variable climate. Consequently, recommendations are often conservative, leading to unrealised potential yields, protein content and thus lost opportunity. In developing the factsheets for managing wheat in the previous project, advisers and growers often demonstrated difficulties in accurately predicting a N response from soil tests and lacked confidence in predicting achievable yield. Providing tools to assist advisers in their crop input recommendations will form the basis for designing an experimental and modelling approach and identifying extension activities and outputs to be delivered within Output 3 of a new GRDC funded National HRZ project.

Concluding Remarks

The HRZ has the potential to produce far higher grain yields for wheat and canola than are currently achieved. Field experiments and modelling indicate that crop yields in the HRZ could be doubled through the introduction of better adapted germplasm and improved management practices. An increase in wheat and canola yields of 50% above those currently achieved by growers has the potential to contribute an estimated $1.2 B to the grains industry.

This report has identified that a key reason for current crop yields in the HRZ of southern Australia being below their known potential is due to insufficient application of inputs, in particular nutrients. Field trials conducted by Southern Farming Systems clearly demonstrate that with adequate inputs, the predicted yield potential of crops exceeding 8 t ha^{-1} is attainable. Information attained from growers and consultants in interviews leads to the conclusion that for a variety of reasons farmers are targeting yields of around 5 t ha^{-1} (far less than their potential) and are applying a level of inputs commensurate with that yield target.

Up-front input costs are high, and with fertiliser application being the highest variable cost in a cropping enterprise, there appears to be a reluctance to apply higher levels of fertiliser to close the gap between actual and potential grain yields. This report is the first step in an approach to address this reluctance by identifying gaps in current knowledge which limit the ability of growers and advisers to confidently predict input requirements and associated risks for crops with high yield potential in the HRZ. This information has been used to design a research program aimed at lifting grower's confidence in determining crop response to higher levels of inputs, hence lifting yields up towards their yield potential. The final products of this program will be simple tools for use by growers and advisers that allow the understanding of the economic benefit of each unit of input, specific to their region.

As identified in this report our ability to make nutrient recommendations in the HRZ through using existing information is limited. For some crops and nutrients, particularly canola, there is almost no data in the HRZ on which critical nutrient values are defined for the high potential yields of this zone. Our research program will use a mixture of targeted paddock surveys, omission and response curve plots to help fill these gaps in knowledge for wheat and canola production in the HRZ, identifying the extent of nutrient deficiencies in different HRZ regions. This information will allow a modelling and economic program to determine locally specific marginal returns per unit of input applied and thus inform the level of fertiliser application at a financially optimal level on individual farms. This modelling effort differs from past modelling efforts which have focused specifically on yield response to additional nitrogen applications. It will consider a balanced fertiliser assessment of N,P,K and S and their differential impact on crop response. This will determine the yield response and production risks associated with nutrient inputs for integration into the economic interpretation framework. This analysis will need to be flexible enough to consider differing market and seasonal drivers to inform current farming decisions into the future. This approach will attempt to explore and explain the observation that farmers are using fertilisers at lower than expected rates in the HRZ, and not achieving the full yield potential. Ultimately this analysis will allow to us to develop a tool to help agronomists allocate fertiliser between various crops and the optimal level and mix of fertilisers to allocate to individual crops.

Factors constraining current yields can vary greatly across the HRZ depending on soil type, climate and seasons, highlighting the need for integrated grower recommendation packages, targeted specifically to their locality. These packages developed for use by grower and advisers need to improve their understanding of how crop potential is related to the level of inputs applied. They also need to account for the diverse range of limiting factors across landscapes along with seasonal variations to improve their understanding of the risks and benefits involved. As advisers are best placed to understand their own needs and that of their clients, development of 'rules of thumb' and simple tools will need their input to ensure they are useful in assisting their client's decision process regarding the economic response to different levels of inputs. The overall outcome of implementing this type of research would be that advisers can make more informed decisions using the tools developed to predict the input requirements which match the yield expectations for wheat and canola while understanding the costs and returns, variability (seasonal and location) and risks associated with their yield target.

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