FINAL REPORT

CSO205

Maximising the efficiency of potassium and nitrogen use and profits by matching supply to crop demand

PROJECT DETAILS

PROJECT CODE:	CSO205
PROJECT TITLE:	MAXIMISING THE EFFICIENCY OF POTASSIUM AND NITROGEN USE AND PROFITS BY MATCHING SUPPLY TO CROP DEMAND
START DATE:	01.07.1999
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Summary

Crops in Western Australia (WA) have relied on natural soil reserves of potassium (K) for their nutritional requirement since land clearing. This practice is unsustainable because K is a major nutrient required in relatively large amounts by crops and WA wheatbelt soils are old, coarse textured and low in K. The lack of K fertiliser use in crops until recently has resulted in the depletion of the natural soil reserves and the onset of increasingly frequent cases of K deficiency, especially on coarser textured soils. This problem can be solved by using K fertiliser. The management of fertiliser K is, however, hampered by spatial variability of grain yields and soil test values that vary by a factor of approx. 10 within the paddock. This gives rise to spatially variable fertiliser requirement due to variations in both supply of nutrient from soil (as indicated by soil test values) and demand (as indicated by biomass production and grain yield). The same problem occurs with the management of fertiliser nitrogen (N). Uniform application of fertiliser inevitably leads to inefficient fertiliser use and potential offsite impact, as some areas of the paddock require more, whereas others require less than the amount applied.

The aims of the project were to:

(1) Develop methods of mapping the availability of K and N at paddock scale using knowledge of spatially variable independent soil parameters;

(2) Determine the corresponding spatial variation of K and N demand and uptake, by assessment of mid-season growth and off-take;

(3) Compare patterns of demand and supply to develop better K and N management and crop rotation practices.

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Conclusions

The wheat requirement for K can be predicted with the decision support system (DSS) from the soil test value for Colwell K and the size of the crop. The predicted K requirements were in good agreement with wheat responses measured in paddock scale experiments. Lupins were generally non-responsive to K. The DSS can be applied for uniform K application in paddocks and zones and for full variable rate (VR) application. Colwell K can be measured cost effectively by chemical analysis for uniform paddock and zone applications. Chemical analysis is too expensive for VR application. In this case, Colwell K can be estimated by gamma ray emission for non-gravelly and non-rocky sites. The gravelly-rocky sites are normally well supplied with K derived from weathering. Gamma emission can also identify zones of soil organic matter (SOM) content and hence of supply of soil mineralisable N. Crop size needed for theDSS can be estimated from anticipated seasonal rainfall by applying the French and Schultz equation, or its modifications for soil types found in the paddock or the zones. For VR application, the paddock average yield can be distributed spatially using historical yield, or its surrogate Normalised Difference Vegetation Indicex (NDVI). This spatially distributed yield refers to past yield performance. It should be used in conjunction with measures of landscape properties that identify inherent suitability for cropping. Gamma emission provides a cheap means of measuring clay content in the landscape and hence: (1) Colwell K and; (2) plant available water (PAW), which is a key driver for achievable yield. Discrepancies between yield and gamma emission maps should help to identify and manage limitations to yield.

The Weight of Evidence model provides a tool to use yield, or its surrogate NDVI, plus independent layers of evidence (e.g. gamma emission) to identify yield performance zones. This zoning should be a one-off cost, as these zones are relatively stable due to inherent landscape properties which simplify fertiliser recommendations.

Financial analysis of the benefits of K use for a relatively uniform paddock with consistently low Colwell K values showed a gross margins increase of $37 per hectare for 2000-02. In another paddock where the soil test value for K and yield were more variable, uniform application of K was less beneficial ($8.50/ha for 2000-01). Application of K only where it was required in the lowest yielding zone resulted in a financial gain of $77/ha (for 2000-01) for 30% of the paddock. This gain resulted in decreased financial loss from cropping the poor performing zone. This strategy should be evaluated against the financial and environmental benefits of land retirement. The gross margins do not include the cost of zoning of approx. $20/ha. This cost could be repaid in two to three years, assuming that the benefits could be extrapolated to the farm. All experiments received a groweracceptable control N application of 25kgN/ha. Experimental crops in 2000-02 did not respond to additional N in these low rainfall years. This lack of response is in agreement with SPLAT model predictions for N requirements.

Successful communication through the rural media, grower meetings, partnerships with industry and the Department of Agriculture Western Australia (DAWA) led to increased grower awareness of the risk and adverse impact of K deficiency on yield. The ensuing rapid adoption of K use will benefit the grains industry by minimising unsustainable mining of the soil K reserves and by increasing profits.

Recommendations

Growers should identify and remedy K deficiency by applying K. The DSS for K will assist by recommending K application to match the soil Colwell K value and the achievable yield of the site. The recommended rates of K are usually in excess of crop removal, which are typically 4kgK/t wheat and 8kg K /t lupins. This partly makes up for long term K depletion. Maintenance application of K equal to the amounts removed in harvested materials should be used in subsequent years to prevent reversal to deficient yield limiting conditions. For this reason, the maintenance application should also be used in soils with just sufficient Colwell K values where the DSS would not recommend a K application based on unlikelihood of response.

The traditional soil test for Colwell K used in paddock and zone situations is too expensive for full variable rate application (VRA). Gamma-ray should be used in this case. The additional benefits of gamma emission measurement are; (1) it estimates plant available water (PAW) and hence site specific achievable yield, (2) it identifies zones of soil mineralisable N supply, and (3) discrepancies between gamma emission and yield maps may help uncover and solve management issues limiting yield. Mid Infra-Red spectrometry provided a cost effective method for more intensive determination of soil organic matter (SOM) and total N content. The French and Schultz equation provides a simple means of determining achievable yield. The achievable yield can be distributed spatially using past yield maps, or its surrogate NDVI, checked against gamma emission maps. The weight of evidence model is a convenient tool to use spatial data layers to zone the farm. This model can also be used to determine land use options to optimise productivity and management outcomes.

The cost of information required to determine the extent and underlying cause of yield variability (yield plus gamma maps costing approx.$45,000 per farm) seems large, but can conceivably be repaid within three years if the benefits measured in paddocks are representative of the farm.

Seasonal conditions during the past few years did not allow response to N to be measured. DAWA has worked for many years on the SPLAT model to make N recommendations. SPLAT, or its more recent version (Select Your Nitrogen)should be used to determine N requirements.

Integrations with the fertiliser industry were an important contributor to the successful adoption of our findings by growers. Considerations should be to continue to involve the industry and benefit from its potential to contribute through an extensive network of country-based agronomists.

Outcomes

Economic Outcomes

Alleviation of K deficiency is expected to improve yield and profits. Because of spatial variability, these benefits are magnified by more targeted application of K where it is most required.

Environmental Outcomes

The Land and Water Audit identified K depletion as a threat to the sustainability of cropping in WA. The current rapid adoption of K use generated by our work will reverse the degradation of our natural resource base and help solve the land degradation issue identified by the audit.

Social Outcomes

It is expected that the economic benefits would translate to social benefits in terms of local economic activity, jobs and less pressure to migrate to urban areas.

Achievements/Benefits

For more details, see Attachment 1.

One of the principal outputs of this project is a DSS for determining K requirements. This DSS can be used for uniform paddocks or zones and VR application. The model takes account of soil test values for K and of achievable crop yield at those spatial scales. The DSS estimates of fertiliser K requirement were in good agreement with wheat response to K measured at the paddock scale. Lupins are generally non-responsive to K. In its simplest form, K fertiliser requirement for paddock and zone application can be read from a graphical form of the model. In its electronic form, the model provides recommendations for VR application based on maps of soil available K and of achievable crop yield. Details of the DSS are available in the Australian Journal of Experimental Agriculture (Wong et al. 2001). The field experiments included N treatments applied as a chequer board design, perpendicular to the K treatments, in order to test DAWA's SPLAT model for N recommendation. The minimum rate of N fertiliser acceptable to the growers for the control treatment was 25kg N/ha. SPLAT did not recommend additional N applications above the control for the drought-affected conditions. This recommendation by SPLAT was in agreement with the experimental results where wheat did not respond to additional N applications.

The DSS for K requires input for soil available K. This can be measured cost effectively by chemical soil analysis for uniform paddocks and for management zone situations where the number of soil samples is small. Chemical soil analysis is too expensive for VR application. In order to address this issue, a proximal sensing method was developed for mapping soil available K expressed as Colwell K or exchangeable K. This method measures the emission of gamma ray from the natural K-40 abundance of soil available K. The method works well in WA soils devoid of gravel and superficial rock (Wong and Harper, 1999). It suffers from interference in soils containing gravel and superficial rock because of gamma ray emission due to non-available K trapped in these materials. These areas of superficial rock and gravel were identified from measurements of gamma emission from thorium contained in these materials. The regression equation for exchangeable K (y) where the gamma method worked well was $y = 1.02x + 48.7$, $R^2 = 0.75$; where x is the gamma emission counts from K-40. The inability to map soil available K accurately in the gravelly/rocky areas should not hamper the prediction of fertiliser requirement, as the gravelly/rocky areas are typically rich in available K (presumably weathered from gravel and rock) and can be mapped as low risk from K deficiency. The data for mapping rocky gravelly areas is normally acquired at no additional cost, as gamma ray surveys normally measure emission from K, thorium and uranium simultaneously. Mineralisation of leguminous crop residues and of soil organic matter (SOM) (measured as soil organic carbon (SOC) or total N) supplies N to crops. Input from leguminous crop residues can be estimated from yield of the lupin phase. The spatial patterns of SOC and total nitrogen (TN) contents were visually similar to those of the gamma emission from K-40. Zones of low, medium and high SOC and TN contents could be identified readily from the gamma emission map. Analysis of the data using non-spatial regression statistics showed that the relationships between gamma emission for K and SOC or TN were poor. However, if direct measurements are needed, the cost of measuring organic carbon (OC) and TN can be minimised by using recently developed and cheaper analysis by Mid Infra-Red Spectroscopy.

Estimates of achievable yield are also required to make a fertiliser recommendation. The paddock average, or zone average, achievable yield was determined from the anticipated seasonal rainfall using the French and Schultz equation. For VR application, this paddock average yield was distributed spatially across the paddock according to the spatial pattern of historical yield or its remotely sensed surrogate, the NDVI, or according to a grower's hand-drawn map showing the relative yield performance of the paddock. Field measurements showed that the fresh wheat biomass was linearly related ($R^2 = 0.87$) to late August NDVI for fresh biomass values up to 20t/ha. The NDVI was saturated above this biomass value. For lupins, the linear regression equation was improved by plotting the log of fresh biomass values against the late August NDVI ($R^2 = 0.72$). The NDVI was saturated at a lupin fresh biomass of 12t/ha. The historical yield data, NDVI and grower's knowledge represent past yield performance, which may or may not be related to the inherent site specific achievable yield of the paddock. The causes of yield variability were investigated by measuring plant available water (PAW) in a range of yielding zones within the paddock and by modelling crop yield using the Agricultural Production Systems simulator (APSIM) for a range of seasonal and fertiliser N management scenarios. The site specific yield performance at grower Rex Heal's property was linearly related to PAW and APSIM modelling showed that the past yield performances in five contrasting yielding zones were mostly driven by this moisture retention property of the soil. The simulations for the past 100 years rainfall data showed that the poorest zone consistently ranked the lowest throughout the simulation runs, in spite of N additions. Similarly, the best performing zone consistently ranked the highest throughout the simulation runs. Moisture retention down the soil profile cannot be altered in a cost effective way by current management techniques and therefore its consequence on yield potential is an inherent property of the landscape. It is therefore justified to use past yield performances in order to gauge how much fertiliser to apply, because yield was driven by a relatively permanent property. It is conceivable that past yield performances may have been coloured by manageable limitations, such as soil acidity, weed infestations etc. These possibilities were monitored by recurrent crop checks and soil checks carried out by DAWA. These checks avoided the chicken and egg situations of under-estimating crop fertiliser requirement because of poor past crop performance.

The cost of measuring PAW is very high. A method of predicting PAW was identified that, in non-gravelly/non rocky soils, is governed by the soil clay content. PAW could be predicted because of the strong correlation between gamma ray emission and clay content. The regression equation for PAW (y) for non-gravelly/non rocky areas was $y = 0.36x + 52$, $R^2 = 0.69$. The correlation between gamma emission and PAW meant that gamma emission itself could be used to predict the inherent spatial variability in yield performance. Discrepancies between yield and gamma emission maps should help to identify and manage limitations to yield.

Another important output is a method for defining management zones based on the Dempster Shafer Weight of Evidence model. The model uses yield maps, or its surrogate NDVI, plus independent layers of evidence to identify underlying landscape performance for cropping. These independent layers of evidence include EM, DEM, gamma-emission maps and grower knowledge. The layers of evidence were weighted according to the strength of their support for cropping performance. The weights were derived from expert knowledge and from statistical relationships between the layer of evidence and the underlying causes of yield variability. The model is flexible and deals easily with multidisciplinary data sources. This work was presented at the 4th European conference on Precision Agriculture (PA) (Wong and Lyle, 2003).

Financial analysis was performed to quantify the benefits of K use. For a relatively uniform paddock at one grower's property, (mean exchangeable K = 18.6mg K/kg soil, standard deviation = 6.1, standard deviations of yield ranged from 0.33 to 0.55t/ha in 2000-02), a uniform application of 25kg K/ha resulted in an increase in gross margin (GM) of $37.30/ha (from $ 4.30 to $101.60/ha) for the three years of experiments (2000-02). It is not possible to extrapolate those gains to the whole farm because of lack of achievable yield and soil test values. Visual inspection of satellite imagery for the whole farm, however, suggests that the cropping area is relatively uniform and that the experimental paddock was relatively typical of the farm. The gains from K use here could potentially be large. Uniform application of K is often not optimal. An experiment on a more spatially variable paddock on another property (mean exchangeable K = 43.9mg K/kg soil, standard deviation = 48.1, standard deviations of yield ranged from 0.86 to 1.14t/ha in 2000-02) showed that uniform application of K resulted in an increase in gross margins of $8.50/ha over a two-year period (2000-01). The yield increase due to K application only occurred in the lowest yielding zone (yield t/ha) equivalent to approx. 30% of the 70ha paddock. The increase in GMs in the responsive zone was $77/ha (from -$203/ha to -$126/ha) over the two-year period. It must be noted that 2000 was the driest year on record and the loss on the low yielding (low PAW) areas was somewhat inflated. Assuming that the lowest yielding zones are kept in production and that the paddock is typical of the 2000ha farm, then the financial benefit of targeted K use on farm would be to minimise loss by $45,000 over the two-year period. There is an additional benefit of $17,000 from applying only maintenance rates of K equal to crop removal in non-responsive zones. This calculation assumed that the grower knew where the K deficient responsive zones were. The financial benefits decrease in proportion to the cost of additional data, such as yield maps and satellite imagery, used to identify the zone. This project has shown that the cost of zoning the whole farm, plus soil analysis, was approx. $40,000 ($20/ha). This is a one-off cost, as the zones are driven by relatively permanent landscape properties. Although those benefits should improve in subsequent years, due to improved seasonal conditions and paid-off zoning costs, the philosophy of using fertiliser for loss minimisation should be balanced against the financial and environmental benefits of retiring the poor performing land from production.

The project's communication achievement increased grower awareness of the risk of K deficiency and of the benefits of K. This has led to rapid adoption, evidenced by a rapid increase in K use in WA from 64kt in 1996 to 128kt in 2002, even in drought affected years. The communication strategy included close collaboration with the fertiliser industry, organisation of field days and the publication of frequent reports in the rural media and at Crop Updates. This rapid adoption of work benefits the grains industry by making it more sustainable in relation to depletion of the already small reserves of natural soil K. The industry now has a graphical (for paddock and zone application) and electronic (for VR application) method to determine if a site is likely to respond to K, how much K to apply and likely response and benefits.

The additional benefit of this project to the grains industry is the development of methods to underpin the development of PA. This includes the: (1) development of cheaper methods to map soil properties, such as PAW and available K, using spatial data sets; (2) use of satellite imagery to determine crop biomass as a possible surrogate for yield maps; and (3) application of the Weight of Evidence model to delineate zones for fertiliser and land use management.

Other research

The Weight of Evidence model provides a powerful tool for zoning fertiliser management and land-use options to optimise productivity and management outcomes at farm to catchment scales. The goal should be to gather several farms to put the zone management and land use options to the test at a farm scale with regard to economic and environmental outcomes. Some of the major costs associated with precision agriculture (PA), such as the purchase of a yield monitor, computer and software, are incurred at farm scale. Additional data layers, such as air-borne gammaemission surveys are more costeffectively done at a farm scale. For these reasons, the costs and benefits of site specific management should be measured at farm scale to evaluate PA more accurately, because it may not be reasonable to extrapolate paddock benefits to the farm. The gamma emission measured in the GRDC PA Initiative (SIP 09) should be compared with yield maps in order to uncover and manage potential yield limitations.

Research into satellite imagery is an important step towards quantifying crop biomass and yield remotely. Premature NDVI saturation needs to be overcome by investigating the application of other indices for predicting biomass and underpinning the potential for within-season agronomy, aimed at minimising risk in input investment and optimising yield. Further research is needed to understand the spatial relationships between biomass and yield in order to diagnose and manage the causes of loss of dry matter conversion to grains, expressed as spatially variable harvest indices.

Additional information

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