Grains Research & Development Corporation

Final Report

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1. Project Information

GRDC Project No: DAQ00148

Line of Business: Practices

Program: Agronomy, Soils and Environment

Project title

Defining critical soil nutrient concentrations in soils supporting grains and cotton in Northern NSW and Queensland

Commencement date	Completion date	Number of years
01/07/2009	30/06/2012	3.00

2. Contact Information

Project Supervisor Contact

Title	Initials	First name	Family name (Surname)
Dr	MJ	Mike	Bell

Position

Principal Research Fellow - Soils and Farming Systems

Name of organisation

Queensland Alliance for Agriculture and Food Innovation, The University of Queensland

Australian Business Number (ABN) *if applicable*

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Administration Contact

Title	Initials	First name	Family name (Surname)
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Position

Research Administration Officer (Science 2; QAAFI)

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3. Budget Summary

Financial Year	2009 | 2010 $	2010 | 2011 $	2011 | 2012 $	$	$	$	Total $
Total GRDC $ Agreed (excl GST)	372,533	376,166	369,996	0	0	0	1,118,695

4. Project Summary

The project focussed on phosphorus (P) and potassium (K) status of northern cropping soils. Stores of P and K have been depleted by crop removal and limited fertiliser application, with depletion most significant in the subsoil. Soil testing strategies are confounded by slowly available mineral reserves with uncertain availability. We have assessed the utility of new soil tests to measure these reserves, quantified their availability to plants and undertaken a regional sampling strategy to identify areas of greatest P and K deficit. Fertiliser application strategies for P and K have been tested and the interactions between these and other nutrients determined in a large field program.

5. Outcome Benefits

The main benefits of this project will be Economic and Environmental. Northern dryland grain and cotton cropping systems have been running negative nutrient budgets for many years. Although fertiliser inputs, particularly N, have risen substantially, the soil nutrient bank is being depleted by the equivalent of $100-$300/ha/year of nutrient. There is increasing evidence of nutrient limitations to crop yield and reduced efficiency of water use. Fertiliser use in irrigated cotton cropping systems more intensive, although guidelines for crop P and K requirements are limited and optimised application strategies poorly developed. Soil sampling and analytical methods to quantify the extent of fertility decline and to better determine when additional fertiliser input is warranted will allow growers to develop sustainable nutrient management programs.

Once a nutrient limitation or limited nutrient reserve is detected, response to additional fertiliser input needs to be clearly demonstrated before additional investment is made. The field program conducted has clearly demonstrated that consistent (and sometimes quite large) grain yield responses can be derived when the right combination of fertiliser nutrients are applied in the right place in the soil profile. We have recorded individual crop yield increases of 10-70% in response to additional fertiliser application beyond commercial practice, with responses of 20% more common. Additional gross return can be as high as $400-$800/ha in high yielding or high value crops. We have also shown that the residual value of deep P applications is excellent, with responses recorded over 5-6 consecutive crop seasons. We have demonstrated effective P application strategies in terms of placement and band spacing, although at this stage we have not developed rate-response functions so that the amount of nutrient addition can be optimised for different soils and systems. Similar work with K is less well advanced, although progress has been made.

The situation with irrigated cotton systems is less well advanced. We have shown the soil K requirement for cotton is 2-3 times as great as for grain crops in lighter soils, but we have yet to demonstrate K responses in the alkaline clays on which most of the crop is grown. The need for deep placement in such systems has not been effectively demonstrated, given the more frequent occurrence of tillage and the concentration of fertilised soil in raised beds, effectively delivering 20-30cm of homogenised and nutrient-enriched topsoil. Irrigation water ensures better root access to these layers. Our field and glasshouse experiments have shown poor ability of cotton crops to effectively access banded P and K fertilisers. We have developed mechanised harvesting capability and the capacity to process large whole plant samples to measure fertiliser nutrient recovery, so we are well positioned to undertake more detailed investigations in this system

6. Pesticide and Herbicide Research

Did this project conduct research on pesticide and herbicide products?

No ☑

Yes ☐ List the active ingredients, rate and timing

7. Outputs

Reproduce any outputs not previously reported against

Output 1

Planned delivery date	Achieved
30/06/2011	Yes

Description

Quantification of the size and availability of P and K reserves in the major grains/cotton growing soils of the northern region.

Achievement prior to this report

Mineralogy work completed. ScARP soil collection accessed to add to regional P and K database. Studies on availability of P reserves finished and those on TBK reserves continuing. Cotton and sorghum grown in glasshouse column experiments.

Achievement for this reporting period

Crop assays on effects of CEC on critical soil K completed for maize. Studies of soil P reserves are complete and work on availability of TBK reserves underway. Mapping of regional P and K data conducted

Achievement of commercialisation details

NA

Non-achievement details

Output 2

Planned delivery date	Achieved
31/12/2011	Yes

Description

Diagnostic criteria that can be used to predict the need for P and K fertilizers and support effective fertilizer use efficiencies in the grains and cotton cropping systems.

Achievement prior to this report

Glasshouse experiments to quantify availability of subsoil BSES P complimented by fertilizer responses in 25 site years from field sites. Another 5 K field trials have beer conducted, and complimented by glasshouse assays to determine critical soil K for different background cation ratios. Soils for final study of effects of CEC collected and prepared for pot trials

Achievement for this reporting period

A further 7 field site-years conducted and glasshouse trials for subsoil P and K completed. Field program completed with harvest of wheat and chickpea crops and soil test-crop response data summarised. Interim soil test guidelines presented at 2012 GRDC Updates.

Achievement of commercialisation details

NA

Non-achievement details

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Output 3

Planned delivery date: 30/06/2012

Achieved: Yes

Description

Determine the most effective P and K fertilizer application strategies (form, placement and timing) in soils with low background nutrient status, including the residual value of those nutrients for subsequent crops.

Achievement prior to this report

Large field program continued, with new sites focussing on P and K placement strategies and PKS interactions. Older sites monitored to assess residual value of P and K in subsequent seasons.

Achievement for this reporting period

Trial program completed after harvest of 2012 winter crop. Summation of P placement results in 2012 Agronomy Conference paper. Glasshouse studies suggest bandec K applications not very effective, but field trials needed to confirm. Demonstration of NPKS interactions having large yield impacts at some locations.

Achievement of commercialisation details

Non-achievement details

8. Milestones

Milestone number: 1	Planned achievement date	Achieved
	30/11/2009	Yes

Description

Samples of regional 'problem soils' collected from major cotton and grain growing regions analyzed, probable limitations identified and representative subgroups selected for detailed analysis. All results added to existing soils database

Achievement prior to this report

Trials established on problem soils have allowed exploration of soil test – crop nutrient uptake relationships in contrasting seasonal conditions. A limited number of regional testing was conducted through agribusiness and advisor linkages, and existing database information was mapped.

Achievement for this report

Regional soil collection has concluded, and analysis of the NSW SCaRP soil collection has been completed. The soils database is now being consolidated.

Milestone number: 2	Planned achievement date	Achieved
	30/06/2010	Yes

Description

More in-depth analyses conducted on problem soils and soils collected in the Healthy Soils and DAQ00084 projects to understand the regional distribution of P and K stocks in major cropping soils of the northern region.

Achievement prior to this report

Attempts to link the analytical data to regional soils maps have been unsuccessful, showing that simple relationships between soil types and P and K reserves do not exist. Further work exploring mineralogy of slow release P reserves may provide some advances.

Achievement for this report

As a regional assessment, the frequency of fertiliser responses are P >> S > K. P deficits are widespread, with the relatively frequent responses to S possibly linked to recent high rainfall years. Many soils low in K but not consistently fertiliser responsive. Strong interactions with root activity and soil volume explored, so wet conditions exacerbate occurrence.

Milestone number: 3	Planned achievement date	Achieved
	30/06/2011	Yes

Description

Data analyzed and report on the size and availability of P and K stocks in the major cropping areas of the northern region completed and submitted for publication.

Achievement prior to this report

Regional soils integration did not provide insights into prediction of P and K status. Further soil collection and analysis initiated by accessing other project and agribusine samples to fill gaps in regional coverage. Current indications are that the far south and central west NSW have fewer P and K issues than from Narrabri north.

Achievement for this report

Neither portable XRF or MIR offer potential for rapid ID of slow release P and K reserves. A paper on availability of slow release P is in review at technical journal. An interim report on the current understanding of slow release P and K and the most promising diagnostic techniques are provided as an attachment. Technical papers on slow release P are in preparation.

Milestone number: 4

Planned achievement date: 31/12/2010

Achieved: Yes

Description

Chemical fractionation/crop exhaustion/fertilizer recovery studies on representative soils from the regional collection completed and sources of plant available P and K identified.

Achievement prior to this report

Plant available P determined for all soils and correlated to other laboratory assays of P availability. Analysis of depleted P soils using soft X-ray spectroscopy has identifi Ca phosphate dissolution as the primary source of slow release P. Depleted soils fertilized to determine fate of fertilizer P.

Achievement for this report

Fate of fertilizer P quantified. Laboratory and glasshouse studies to quantify availability of reserve K commenced and analyses conducted midway through K exhaustion by plants. This work is being completed in a subsequent project.

Milestone number: 5

Planned achievement date: 30/06/2011

Achieved: Yes

Description

Relationship between diagnostic indicators and plant responses completed for P and K under controlled conditions in laboratory and glasshouse studies

Achievement prior to this report

Exhaustive plant P removal completed. Colwell P is the best indicator of available P under high demand conditions. Further P removal using FeO strips does not indicate plant available P under high demand conditions. Studies with K availability in a smaller collection of soils based on exchangeable and TB-K commenced. Methods to explore impact of varying background cation ratios on K supply to plants developed.

Achievement for this report

Fate of fertiliser P in depleted soils assessed. Further analysis of P experiments suggests BSES P and FeO P can be used to indicate plant available P reserves. K experiments to exhaustively deplete soils of available K underway. Critical soil solution K for plant uptake determined and method to quantify available and non-available developed. Effects of cation ratios on plant K acquisition completed.

Milestone number: 6

Planned achievement date: 31/12/2011

Achieved: Yes

Description

First stages of in-field strip trials to validate soil test predictions of P and K requirements initiated and results interpreted

Achievement prior to this report

A further 9 field trials were established. PKS screening trials have been conducted in Central and southern Qld and NNSW, while a further 5 studies investigating P and fertilizer placement strategies and product comparisons (liquid v granular P) were established. Prior sites were monitored to assess residual value.

Achievement for this report

Field trial program completed at the end of the 2012 winter crop. Some sites carried forward into UQ00063. Crop responses consistent with expectations for P but responses to S uncertain due to lack of critical values and variable for K. Further work needed to develop robust decision support aids.

Milestone number: 7	Planned achievement date	Achieved
	30/06/2011	Yes

Description

Glasshouse trials investigating plant responses to different P and K application methods completed and field trials initiated.

Achievement prior to this report

Glasshouse P trials have followed a sequence of fababeans/cotton at UNE and wheat/sorghum in Toowoomba, with all harvested except the final sorghum crop. A small collection of 13 regional soils has been undertaken for a similar study exploring subsoil K supply in soils with differing K pools and CEC.

Achievement for this report

Analysis and write up of the fababean/cotton glasshouse P trials has resulted in a technical paper submitted, with results consistent with lab assays. Glasshouse K trials have been conducted with maize to explore crop response to subsoil K and various enrichment strategies. Data have been analysed and a second crop of cotton grown.

Milestone number: 8	Planned achievement date	Achieved
	31/12/2011	Yes

Description

Field trials initiated to confirm results from glasshouse studies and first season results evaluated and reported.

Achievement prior to this report

Addition of 9 new trial sites for P and K placement, and also PKS interactions, ensures large field program with good coverage of regions, crops (grains v cotton) and fre v residual fertilizer applications. Wet seasons have caused some N limitations but all sites were cropped and some double cropped, placing strain on field program.

Achievement for this report

Summer sorghum and cotton and winter wheat and chickpea crops harvested and results compiled and analysed. Some sites are continuing into UQ00063.

Milestone number: 9	Planned achievement date	Achieved
	30/06/2010	Yes

Description

Results from field and glasshouse studies reported to industry on an annual basis and project annual reporting completed

Achievement prior to this report

Industry reporting continued, with greater exposure of field trial program through field days and farm walks, summer and winter GRDC Updates and features in Landline and Groundcover. Technical paper presented at Soil Symposium and abstracts submitted to agronomy conference.

Achievement for this report

Presentations at Agronomy conference summarised key technical findings. Presentations at GRDC Updates in Goondiwindi (March) and Dalby (Sept) and CCA advisor meeting in Moree (May) covered growers and advisors in NNSW and SQld, and 8 regional field days in CQ provided summaries to those regions. Technical papers are i preparation.

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Milestone number: 10	Planned achievement date	Achieved
	30/09/2012	Yes

Description

Final project report prepared and submitted

Achievement prior to this report

Project extension until 30 Sept and report submission on 20/12/12 and then 28/2/13 requested and approved. Delays associated with glasshouse K studies and processing cotton plant samples for chemical analysis.

Achievement for this report

Final report prepared and submitted.

Milestone number: 11	Planned achievement date	Achieved

Description

Achievement prior to this report

Achievement for this report

Milestone number: 12	Planned achievement date	Achieved

Description

Achievement prior to this report

Achievement for this report

Milestone number: 13	Planned achievement date	Achieved

Description

Achievement prior to this report

Achievement for this report

Milestone number: 14	Planned achievement date	Achieved

Description

Achievement prior to this report

Achievement for this report

Milestone number: 15	Planned achievement date	Achieved

Description

Achievement prior to this report

Achievement for this report

9. Delivery Activity— Publications (may include industry report/refereed scientific paper)

What were the proposed target audiences and/or organisations for the activities/outputs? (e.g. Grain growers, agribusiness, researchers, breeders)

Researchers, fertilizer industry, advisors

Was this activity/output delivered as part of the project?

No ☐
Yes ☑

Date of delivery (dd/mm/yyyy)

31/07/2011

Was there recurring years for this activity/output?

No ☐
Yes ☑ Month and year of activities/outputs

2/2012 and 9/2012

Did this activity/output include third parties?

No ☑
Yes ☐ Name of principal contractor

Was this activity/output funded within the project budget?

No ☐ Details of external funding

Yes ☑ **Include in budget and operating notes.**

Was this activity/output national/regional/local?

National ☑
Regional ☑ Specify region if possible

Northern region

Local ☐ Specify locality if possible

Final summary of the outcome for this activity/output

Papers on P mineralogy in Vertosols, assessing availability of slow release P measured by BSES tests and response to differing subsoil P status and fertiliser application strategies submitted for publication; McLaren PhD thesis submitted; Paper on field fertilizer program presented at Agronomy conference at UNE.

Delivery Activity— Ground Cover

What were the proposed target audiences and/or organisations for the activities/outputs? (e.g. Grain growers, agribusiness, researchers, breeders)

Grain growers and agribusiness

Was this activity/output delivered as part of the project?

No ☐
Yes ☑

Date of delivery (dd/mm/yyyy)

28/02/2011

Was there recurring years for this activity/output?

No ☐
Yes ☑ Month and year of activities/outputs

9/2011 and 2/2012

Did this activity/output include third parties?

No ☑
Yes ☐ Name of principal contractor

Was this activity/output funded within the project budget?

No ☐ Details of external funding

Yes ☑ **Include in budget and operating notes.**

Was this activity/output national/regional/local?

National ☑
Regional ☑ Specify region if possible

Northern region

Local ☐ Specify locality if possible

Final summary of the outcome for this activity/output

Article in Australian Grain (Mar-Apr 2012); Factsheet on Phosphorus nutrition in northern region released in late 2012; Articles in Groundcover in late 2012 on deep fertiliser placement.

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Delivery Activity— Field days/trials/self assessment/presentations

What were the proposed target audiences and/or organisations for the activities/outputs? (e.g. Grain growers, agribusiness, researchers, breeders)

Growers and advisors

Was this activity/output delivered as part of the project?

No ☐
Yes ☑

Date of delivery (dd/mm/yyyy)

11/12/2011

Was there recurring years for this activity/output?

No ☐
Yes ☑ Month and year of activities/outputs

12/11, 2/12, 5/12

Did this activity/output include third parties?

No ☑
Yes ☐ Name of principal contractor

Was this activity/output funded within the project budget?

No ☐ Details of external funding

Yes ☑ **Include in budget and operating notes.**

Was this activity/output national/regional/local?

National ☐
Regional ☑ Specify region if possible

Northern region

Local ☑ Specify locality if possible

Regional production centers

Final summary of the outcome for this activity/output

Spoke at agribusiness field day at Pittsworth in April 2012 and at Crop Consultants Australia meeting at Moree in May 2012 on deep nutrients and fertility decline; field days in Moree in late 2012 on deep placement and multi-nutrient limits; spoke at 8 CQ field days on soil testing and fertiliser responses in Dec 2012.

Delivery Activity— Grains Research Updates

What were the proposed target audiences and/or organisations for the activities/outputs? (e.g. Grain growers, agribusiness, researchers, breeders)

Growers, advisors, agribusiness

Was this activity/output delivered as part of the project?

No ☐
Yes ☑

Date of delivery (dd/mm/yyyy)

31/08/2011

Was there recurring years for this activity/output?

No ☐
Yes ☑ Month and year of activities/outputs

3/12

Did this activity/output include third parties?

No ☑
Yes ☐ Name of principal contractor

Was this activity/output funded within the project budget?

No ☐ Details of external funding

Yes ☑ **Include in budget and operating notes.**

Was this activity/output national/regional/local?

National ☐
Regional ☑ Specify region if possible

Northern region

Local ☑ Specify locality if possible

Sites of Updates in Qld

Final summary of the outcome for this activity/output

Presentations to GRDC Updates in Goondiwindi and Surat in March 2012 and Dalby in Sept 2012. Talks were on multi-nutrient interactions, P and K soil testing and N fertilizer strategies.

Additional Extension Activities/Referred Publications (in bibliographical format)

Bell M, Lester D, Smith L and Want P 2012. Increasing complexity in nutrient management on clay soils in the northern grain belt – nutrient stratification and multiple nutrient limitations. http://www.regional.org.au/au/asa/2012/nutrition/8045_bellm.htm
McLaren T Guppy C Tighe M 2012. A rapid and non-destructive plant nutrient analysis using portable X-ray fluorescence. Soil Sci. Soc. Amer J. 76, 1446-53.
McLaren T Guppy C Tighe M Forster N Grave P Lisle L Bennett J 2012. Rapid, non-destructive total elemental analysis of Vertisol soils using portable X-ray fluorescence. Soil Sci. Soc. Amer J. 76, 1436-45.
McLaren T Bell M Rochester I Guppy C Tighe M and Flavel R 2013. Growth and P uptake of faba bean and cotton are related to Colwell-P concentrations in the subsoil of Vertosols. Crop & Pasture Sci. (In press).
McLaren T Guppy C Tighe M Moody P and Bell M 2013. The slowly available phosphorus pool buffers readily available phosphorus in Vertosols. Soil Sci. Soc. Amer J. (In review).

Delivery/Path to Market

There is a steady stream of information being released from this project to all levels of industry. This includes growers, advisors, the research community and the fertilizer industry. This takes the form of technical publications, presentations at grower updates and field days, newsletter articles and press releases.

10. Environment/Economic/Social Analysis

Outline the benefits/risks associated with this proposed investment.

Benefits

Include an estimate of the benefit and the scale to which the impact will apply (i.e. ha, tonnes).
Also include likelihood of benefit and proposed extent of the adoption by industry in the project timeframes and beyond.

Risks

Include likelihood of risk and management options.

Environmental Benefits

Efficient and effective nutrient management strategies are the key to sustainable cropping systems in northern Australia. Developing appropriate soil sampling and laboratory analytical strategies to diagnose nutrient deficiencies or long term fertility decline, and fertiliser application strategies to maximize crop recovery are keys to maximizing adoption of improved practices

Environmental Risks

The stratification of immobile nutrients like P and K (maintenance or enrichment of topsoils but subsoil depletion) means that occasional tillage will need to be adopted in cropping systems that are currently largely, if not completely, direct drill. The loss of soil cover and resulting erosion (and possible soil health) risks can be minimised by effective placement strategies.

Economic Benefits

There are strong economic benefits of ensuring the nutrient deficits do not limit the response to available moisture. Responses to improved P, K and S increase yields by 25-30% on responsive soils and responses can be as high as 70%, with gross returns typically $150-$300/ha. The residual value of nutrients and costs of optimized application strategies will determine net benefits.

Economic Risks

The main economic risk is from growers and advisors adopting a deep placement application strategy without conducting the necessary soil testing to ensure responses will be achieved. Variability in soil nutrient reserves is considerable, even within similar geographic areas on similar soil types, so appropriate testing is essential. Extra nutrient inputs may challenge short term farm profitability

Social Benefits

Understanding the nutrient balance in different crops and rotations and the application strategies necessary to address emerging nutrient deficits will allow growers to confidently develop long term nutrient management plans for their enterprise, and contribute to maintenance of all land use options

Social Risks

The short term challenge of the cost of additional nutrient inputs may preclude growers adopting these strategies, with continued decline in native fertility, and ultimately the loss of land use flexibility that accompanies a degraded soil resource. This will affect land values, regional businesses and communities.

11. Overview of Project Achievements

This overview of achievements is presented in relation to project outputs.
Output 1 - Quantification of the size and availability of P and K reserves in the major grains/cotton growing soils of the northern region.
We have undertaken an extensive soil sampling and lab analysis campaign, using both resources in this project and also by adding value to sampling campaigns undertaken in other research projects (eg. L&WA Healthy Soils, SCaRP), or by agricultural consultants and regional soil surveying teams (the latter in NWNSW). This has resulted in a region-wide database that covers most major cropping soils and districts in the NGR, and that contains subsoil analyses from > 800 locations, including ca. 100 trial sites from the current and previous GRDC-funded nutrient projects. The locations of most of these sites are shown on Qld (1) and NSW (2) maps attached to this report. In summary, there are some clear trends that emerge from these analyses –
(i) There is a more consistent occurrence of (apparent) slow release reserves of K than P across the region, although there are a number of regions (eg. Central Highlands of Qld, northern Darling Downs, NE slopes in NSW) where K reserves are minimal.(ii) The occurrence of P reserves is patchy, and probably linked to geology/native vegetation. Low reserves are encountered in broad swathes of Qld and NE NSW, but the NW of NSW (west of the Newell Highway), the Dawson-Callide flood plains and parts of the eastern Darling Downs have moderate to high P reserves.
While the diagnostic criteria for assessing the presence of slow release P (BSES-P) and K (tetraphenyl borate-K) reserves is settled, and in the case of BSES-P, increasingly well adopted commercially, determining the availability of those P and K reserves to plants has occupied considerable research effort in this project. A technical paper assessing the contributions of Colwell-P and BSES-P to uptake of P by crops of cotton and fababean is attached, along with a more detailed exploration of techniques to relate soil P and K diagnostics to plant availability. In the latter instance, the work is more developed for P than K, although the K work is continuing and will be completed later this year and reported via UQ00063 (grains) and UQ1302 (cotton).
In summary, the work with P has shown that (i) Colwell P provides a good indication of easily available P that can be accessed by a current crop, while slow release P minerals measured by the BSES extract tend to replenish Colwell P in the medium term (ie. between crops). The contribution of these slowly soluble P forms is particularly relevant in the larger soil volumes associated with subsoil root exploration. (ii) While Ca:P ratios in the BSES extractant provided a useful insight into availability of BSES P in Vertosols in the Liverpool Plains area, this relationship did not extend to Vertosols across the region. (iii) A combination of the ratio of BSES P:Colwell P and the ratio of P released to an FeO strip (or possibly a DGT device): BSES P may offer more broadly applicable diagnostic value.(iv) Laboratory analyses suggest TB-K may more effectively detect slowly soluble K reserves than the BSES-P test detects slowly soluble forms of P. However, the strength of the TB-K sink means these reserves may not all be available to plants, and ways of discriminating available and non-available fractions need to be developed. (v) A 2-point K desorption index shows promise from this perspective, and requires further investigation on a wide range of soils and crops before commercial development can be considered. (vi) Both diagnostic methods of detecting slow release forms of P and K are considered occasional (every 5-10 years) characterisation tests to describe soil nutritional status, rather than annual monitoring tests used to guide fertiliser inputs for the coming crop or growing season.
Output 2. Diagnostic criteria that can be used to predict the need for P and K fertilizers and support effective fertilizer use efficiencies in the grains and cotton cropping systems. The project has established an extensive field research program consisting of 10 carry-over sites from the previous SQFS subproject (CSA00013) and 16 newly established field trials, collectively representing 44 crop-years. These comprise 12 cotton crops (5 irrigated and 7 dryland), 12 sorghum crops, 13 wheat crops, 5 grain legumes and 2 other grains. Collectively these sites address issues of subsoil nutrient placement (P and K) and the occurrence of multiple nutrient limitations at a single site, which has been the reason for unexplained lack of P response in a number of earlier studies.
The soil sampling protocol developed to characterise responsiveness to deep placed fertiliser in dryland systems involves 0-10 cm and 10-30cm sampling depths. Site P status was determined from a minimum dataset of Colwell P and PBI in the 0-10cm layer and those analyses plus BSES P in the 10-30cm layer. Site K status was determined by measuring exchangeable cations and cation exchange capacity in both layers, and a TB-K1h analysis in the subsoil. The further refinements to determine availability of both BSES-P and TB-K reserves discussed under Output 1 (FeO-P and K desorption isotherms using tetraphenyl borate) would also be required on the 10-30cm layer. Similar analyses have so far been used in irrigated cotton fields, but on composite 0-30cm samples reflecting the cultivated and homogenised beds/ridges. The contributions to crop P and K uptake from soil layers below the depth of cultivation (ie. below the 20-30cm of planted ridge/bed) have yet to be determined, and so the appropriateness of this sampling strategy for irrigated cotton needs further investigation.
The relative soil P and K requirements of cotton and grain crops, and hence the need for P and K fertilisers, were compared in the individual field sites, in a long term field K trial site near Kingaroy and in glasshouse trials at Armidale, Toowoomba and Kingaroy. The latter were conducted using reconstructed profiles from 18-20 soils with differing P and K status (36-40 soils in total) collected from across the NGR. In rainfed crops responses were affected by seasonal conditions, with a better response to shallow placement in wetter seasons and to deeper placement in drier years. Flooding directly impacted on trials in Qld (2010/11) and NSW (2011/12), while also introducing N limitations in on-farm trials in the following seasons (due to leaching or denitrification losses). This confounding has clouded the

12. Conclusions

Significant progress has been made in all project output areas. We have a clear picture of the regional distribution of P and K reserves across the main cropping soils and regions of the NGR, and so are in a position to be able to better focus our research in regions where continued negative nutrient budgets will have the greatest impact on productivity. We are also increasingly confident in the ability of the BSES-P and TB-K soil tests to quantify potential slow release mineral reserves of each nutrient. Further, we have developed prototype methods that so far seem promising in determining the availability of these slowly soluble minerals to plants – especially in the medium term. However there is further work needed to better test the diagnostic approach for P against a wider range of soils, and to refine the K desorption index method. This work will be essential before these approaches can be adopted by the commercial sector.

We have made significant advances in the development of at least broad guidelines to better define the need for P and K fertilisers for grains crops, and for deep application strategies, and these findings have been promoted to industry in the 2012 GRDC Updates. A more extensive field testing program is required to move beyond these broad response categories for P, and in terms of K, much more intensive study of cation interactions in medium-heavy clays (especially Vertosols) and the K-specific requirements of different grain and grain legume species on these soils is needed. The situation with cotton is much less clear, driven by the apparent inability of this species to effectively utilize concentrated sources of plant-available nutrients like P and K – such as supplied by banded fertiliser application. There is a need to gain a better understanding of the interactions between the cotton root system and the uptake of soil P and K, as well as the most effective application strategies to enable crop recovery of applied fertilisers in both irrigated and dryland systems.

We now have well-developed application strategies to guide deep P fertiliser application in grains, with both the band spacing and positioning between topsoil and subsoil well understood. The difficulty in identification of K responsive sites in heavy clays and the strong buffering of soil solution K activity that inhibits the 'typical' crop luxury uptake process has slowed the development of a similar level of understanding for K. The focus of this research now needs to shift to look at efficiencies of fertiliser recovery and the implications for application rates.

The frequency of occurrence of multiple nutrient limitations at a site, especially in dryland grains cropping areas, represents a significant limitation to effective use of available moisture. We have demonstrated that understanding the possible nutrient interactions in a field is a key to developing an effective fertiliser program, with large increases in potential yields (30-70%) recorded. However, the economics of significantly increased investment in fertilisers in rainfed systems, the interactions between tillage system/volume of nutrient enrichment and the residual value of applied nutrient are key areas for further exploration.

13. Recommendations

- Soil sampling strategies that take into account the demonstrated importance of subsoil nutrient reserves, especially of effectively immobile nutrients like P and K, are essential for the development of effective fertiliser programs and also monitoring long term fertility trends. The strategies would appear to revolve around regular monitoring of shallow (0-10cm) reserves, combined with occasional assessment of deeper layers (10-30cm) in dryland systems. The appropriateness of the current 0-30cm sampling depth for irrigated cotton fields has yet to be confirmed.
- Sparingly soluble soil minerals (either naturally occurring or the reaction products of fertiliser application) are an important buffering mechanism that can replenish the highly labile pools of P and K in the clay soils of the NGR. Quantification of these reserves should be undertaken periodically, and should be viewed as a measure of background soil fertility in the medium term, rather than a measure of nutrient available to the current crop.
- The BSES-P test should form part of the routine diagnostic suite used by commercial laboratories for northern grains soils, in addition to Colwell P and PBI, and is of particular significance in subsoil (10-30cm) layers. The development of a commercially acceptable method of assessing relative availability of these slow release forms of P needs urgent attention.
- There is a need for an expanded effort to quantify availability of sparingly soluble K pools measured by tetraphenyl borate, in addition to that of readily available exchangeable K, in strongly buffered medium-heavy clay soils. This is especially relevant in sodic soils with limited diffusive supply capability.
- A much better understanding of the interactions between cotton root systems and both concentrated and diffuse sources of P and K is needed. This will require an intensive research effort that will form the basis of future fertiliser application strategies in this industry, in both irrigated and dryland production systems.
- Deep placement of immobile nutrients like P and K will form an increasingly important characteristic of fertiliser programs for rainfed cropping in the northern region. Integration of these practices within an (otherwise) reduced or zero tillage system is essential, and will require a clear understanding of the impacts of different application methods on nutrient availability, residual nutrient recovery and broader soil health outcomes. The relevance of deep placement in irrigated cotton systems has yet to be confirmed.
- The obvious frequency of occurrence of multiple nutrient limitations in many clay soils of the NGR requires a significant revision of fertiliser application strategies. This includes likely changes to the fertiliser products used, increased use of multi-nutrient products and a clear understanding of the limitations inherent in these practices in terms of crop nutrient acquisition. Significant research effort will be required to develop the principles needed to shape these practices.

14. Other Research and Development Opportunities

- A subsequent project in the MPCN2 initiative (UQ00063) and another funded by CRDC (UQ1302) are attempting to develop improved soil test-crop response relationships for P, K and S in the NGR. As part of these projects, there will be an opportunity to further assess the 2 point TB-K desorption curve as a way of assessing the relative availability of reserve K, and to further compare the relative advantages of either DGT-P or FeO-P in providing a similar relative measure of availability of sparingly soluble soil P reserves. If either or both of these techniques continue to show promise across a wide range of soils and conditions, there would be opportunities to promote these tests for use in the commercial sector. For quality assurance purposes this would require the development of a 'preferred method' for assessing availability of reserve P and K that can become part of the ASPAC suite of certified diagnostic soil tests.
- This project and precursors have clearly shown that negative nutrient budgets over an extended period of time have eroded native fertility reserves to the extent that increased nutrient inputs will be required to maintain crop productivity and/or flexibility of land use. Given the variable climatic conditions and the increasing cost-price pressures particularly on rainfed producers, this represents significant financial challenges to producers. There is a clear opportunity to revisit nutrient management strategies in these situations, looking for alternate (preferably cheaper) sources of nutrients, improved use efficiencies or changed farming systems that facilitate substitution of legume-derived N for fertiliser N, thus allowing diversion of current fertiliser N budgets to other nutrient forms. The latter option is especially attractive given the (current) low legume frequency in NGR crop rotations and the dominance of N in fertiliser input costs, but would require and extensive evaluation of adapted legume species and their ability to fix atmospheric N and provide net N benefits to the cropping system.
- The likely revision of fertiliser application strategies and the increase in use of multi-nutrient fertiliser products in NGR soils will require some detailed investigation of the limitations of use of these products and application strategies in terms of root growth and nutrient acquisition. Given the need for deep placement and the desire to limit the frequency of intensive tillage operations, it is likely that rates of product applied will be targeting nutrient supply over multiple crops, and so will involve high application rates. We have already demonstrated inhibited cotton growth due to high rates of compound fertilisers in subsoil bands, and so work to define safe application rates and product combinations will need to be undertaken to provide a framework for these new strategies.

15. Attachments

Attachment 1-3. Maps showing sampling locations in Qld and NSW where the P and K reserves have been determined in subsoils of cropping fields.
Attachment 4. Technical report on diagnostic methodology to quantity P and K reserves
Attachment 5. Paper presented at GRDC Updates in March 2012 providing interim guidelines to assess soil P and K fertility.
Attachment 6. Paper presented at Agronomy Conference 2012 on multiple nutrient limitations and deep placement of P and K.

16. Management of Intellectual Property/Commercialisation

Provide a summary of any strategies undertaken or planned to facilitate the protection and / or commercialisation of the project's realised outputs

NA

Provide a list of all scientific or technical papers published, and any patents filed

See Additional Information

Provide a list of any confidential information, if relevant and attach details to this report

NA

17. Details of International Collaboration

Did this project have international collaboration?

No ☑

Yes ☐ Provide details of the international collaborating organisations/people below

Provide details of the international collaborating organisations/people below

Detail the nature of the international collaboration

18. Please use this area to include any additional text to support your report. Please do not include images. You may also attach a document (e.g. Word, Excel, PDF) limited to a maximum of 5 x A4 pages to this Report. Any additional information will be viewed as supplementary data. The report will only be evaluated on the previous sections of this document.

List of technical publications

1. Mike Bell, Phil Moody, Graham Stirling and Nicole Seymour (2010). Challenges to improving the long term sustainability of northern grains cropping systems. Proc., 1st Australian Summer Grains Conference, Gold Coast July 2010.
2. Mike Bell, Phil Moody, Kaara Klepper and Dave Lawrence (2010). The challenge to sustainability of broadacre grain cropping systems on clay soils in northern Australia. Pp. 3088-3091. Proc., 19th World Soils Congress, Brisbane

3. Phil Moody, Mike Bell, Kaara Klepper, David Lawrence and Grant Pu (2010). Implications of minimum till dryland cropping systems for diagnostic P and K soil tests. Pp. 4985-4988. Proc., 19th World Soils Congress, Brisbane.
4. McLaren, T.I., Guppy, C.N., Tighe, M., Forster, N., Grave, P. (2010). Non-destructive element analysis using portable X-ray fluorescence (PXRF) on Vertosol soils in the northern grains region. ASPAC 2010 Annual Conference - the environment, the future. Canberra Nov 29-Dec1, 2010.
5. Phil Moody and Mike Bell (2010). New faming systems pose challenges for diagnostic soil testing in northern Australia. Pp 74-78. Proc., ASPAC 2010 Annual Conference - the environment, the future. Canberra Nov 29-Dec1, 2010.
6. McLaren, T.I., Guppy, C.N., Tighe, M. (2011). Rapid, non-destructive total element analysis 114 using portable X-ray fluorescence (PXRF) on cotton leaf tissue and soybean grain, 12th International Symposium on Soil and Plant Analysis Conference, Chania, Greece.
7. McLaren T, Guppy C, Tighe M 2012. A rapid and non-destructive plant nutrient analysis using portable X-ray fluorescence (PXRF). Soil Sci. Soc. America J. 76, 1446-1453.
8. McLaren T, Guppy C, Tighe M, Forster N, Grave P, Lisle L, Bennett J 2012. Rapid, non-destructive total elemental analysis of Vertisol soils using portable X-ray fluorescence (PXRF). Soil Sci. Soc. America J. 76, 1436-1445.
9. McLaren T, Guppy C, Tighe M, Moody P and Bell M 2012. The slowly available phosphorus pool buffers readily available phosphorus in Vertosols. Soil Sci. Soc. America J. (In review).
10. Bell M, Lester D, Smith L and Want P (2012). Increasing complexity in nutrient management on clay soils in the northern grain belt – nutrient stratification and multiple nutrient limitations. http://www.regional.org.au/au/asa/2012/nutrition/8045_bellm.htm
11. Guixin Pu and Phil Moody 2012. Soil P tests for evaluating P availability in Vertosols and Dermosols of the northern Australian grains region (Oral presentation). Joint SSA and NZSSS Soil Science Conference: Soil Solutions for Diverse Landscapes. Hobart, Tasmania, Australia, 2-7 December 2012.
12. McLaren T, Bell M, Rochester I, Guppy C, Tighe M and Flavel R 2013. Growth and P uptake of faba bean and cotton are related to Colwell-P concentrations in the subsoil of Vertosols. Crop & Pasture Sci. (In press).
13. McLaren, T.I., Guppy, C.N., Tighe, M., Schefe, C.R., Flavel, R.J., Cowie, B., Tadich, A. (2012). Soil phosphate removal by a two-step sequential fractionation procedure in a Vertosol soil using XANES. Soil Research (In review).

Grains Research & Development Corporation

Final Report

19. Plain English Summary for Public Release

Project Title:	**Defining critical soil nutrient concentrations in soils supporting grains and cotton in Northern NSW and Queensland**
GRDC Project No:	**DAQ00148**
Primary Contact:	Dr Mike Bell
Organisation:	Queensland Alliance for Agriculture and Food Innovation, The University of Queensland PO Box 23 Kingaroy QLD 4610 Australia
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Email:	m.bell4@uq.edu.au
Objectives	The project was designed to (i) Quantify the size and availability of P and K reserves in the major grains/cotton growing soils of the northern region; (ii) Develop diagnostic criteria that can be used to predict the need for P and K fertilizers and support effective fertilizer use efficiencies in the cotton and grains cropping systems; (iii) Investigate the most effective P and K fertilizer application strategies (form, placement and timing) in soils with low background nutrient status, including the residual value of nutrients for subsequent crops; and (iv) Communicate these findings to the cotton and grains industries, agribusiness and the fertilizer industry.
Background	Strategies to determine cost-effective nutrient management strategies rely on soil testing to determine the size and rate of change of labile nutrient pools in different soils and cropping systems, as well as increasing the understanding of the rate of nutrient removal. There are a number of limitations with existing soil testing methods that determine the extent of nutrient reserves and the likely responsiveness to fertilizer additions, and these limitations are particularly obvious for soil tests to determine P and K status. There is a strong need to address these soil diagnostic limitations and devise agronomic management strategies to ensure efficient and profitable use of P and K fertilizers in soils in which native reserves are declining.
Research	Soil analyses have been undertaken to determine P and K reserves in major cropping soils across the northern region, with availability of these reserves being assessed by laboratory and glasshouse assays. The ability of soil test diagnostics to adequately reflect plant available P and K is being assessed, while a variety of analytical approaches are being used to determine the key mineral associations with these nutrient reserves and any interactions between background soil fertility and availability of those nutrients to plants. An extensive field and glasshouse experimental program has been conducted to determine the most effective P and K fertilization strategies for grains and cotton, while assessment of the residual benefits of deep-applied P and K are being determined as a precursor to exploring the economics of deep placement fertilizer application

Grains Research & Development Corporation

Final Report

20. Scientific Report for Public Release

Are you required to submit the Scientific Report for Public Release for GRDC Progress and Final Reports?

No ☑

Yes ☐

Use the section headings shown below:

Abstract:
Introduction:
Materials and Methods:
Results:
Discussion:
Conclusion:
Appendices:
Acknowledgements:
References.

Step 1: **Click to go the template on our website**

Step 2: **Attach this Scientific Report to the Progress Report**

21. PRIVACY

The personal information you supply will be held on a database by the GRDC. The information held by the GRDC may also include your particular field of interest and in some cases details of some research projects undertaken. Third parties, such as researchers, federal and state agencies, growers and other members of the public, sometimes ask the GRDC to provide contact details. It is the GRDC's usual practice to pass on the information if it is satisfied that it is for legitimate industry or research purposes.
If you do not want to have your contact details disclosed in these circumstances, please inform us by ticking the box below.

No ☐

22. Certification

Reports to the GRDC should be made by the organisation conducting the research and coordinated through their central administrative area. For example, tertiary education institution reports should be processed through the Registrar or Bursar's office. Ensure the Certification details are complete before the form is submitted electronically. The electronic copy received by GRDC will be the copy that is evaluated.
Ensure that one hardcopy of the electronically submitted form is signed by the Project Supervisor and a duly delegated representative from the research organization.

Send this hardcopy to the GRDC (**Contracts Coordinator, GRDC, PO Box 5367, Kingston ACT 2604**) by the published closing date.

Project Supervisor's signature	Name	Date
	Michael Bell	08/05/2013

Research organisation signature	Name and title of authorised signatory	Date

Date last changed
8/05/2013 1:52:52 PM

Grains Research & Development Corporation

Final Report

Example of Plain English Summary

Project Title:	**Benchmarking Wheat End Product Quality for Black Point Affected Grain**
GRDC Project No:	**BRI105**
Researcher:	Michael Southan
Organisation:	BRI Australia Ltd PO Box 7 NORTH RYDE NSW 1670
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Objectives	To assess the real, as opposed to the perceived effect of black point on milling, flour and end product quality: i.e. benchmark the amount of black point affected grain that can be used to manufacture a range of end products while maintaining acceptable quality standards.
Background	Black point in wheat and durum is caused by an enzymic browing or staining of the germ (embryo) ans surrounding bran tissues of wheat, durum and barley and can occur during dry or wet conditions at harvest. Grain deliveries with black point at levels greater than 3% in durum and 5% in wheat are downgraded on the grounds of marketers' interpretation of customer perception. A greater price reducationare currently around $57-62 per tonne of wheat but can cost growers as much as $100 per tonne. The cost to the Australian wheat industry has been estimated to be on average $9.1 million per year (Source: Grain Statistics 1995-1996).
Research	The first set of experiments were designed to evaluate the impact of blackpoint affected wheat sourced in southern NSW on baking quality as most of the wheat grown in this reagion is used by the domestic milling industyr. The second set of experiments were designed to evaluate the impact of black point affected wheat on some of the end products made by Australia's international markets. As the results of the first revealed little impact of up to 10.4% black point on flour and end product quality a higher level of black point was selected.
Outcomes	Up to an extra 10 million dollars per year could be returned to growers through a better understanding of how to use black point affected wheat. The domestic industry currently uses black point affected wheat without any economic risk to their businesses. The Australian wheat industry neds to take up the challenge to educate overseas customers what black point is and how it can be used for a wide range of products with no impact on quality.
Implications	This study has shown that much higher levels of black point affected wheat can be processed at a commercial scale into flour, bread and noodles than would be indicated by the current receival standards.