FINAL REPORT

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

DAQ00148

Project Details

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Summary

This project focussed on the 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. The utility of new soil tests was assessed to measure these reserves, their availability to plants quantified and a regional sampling strategy undertaken 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 have been determined in a large field program.

Conclusions

Significant progress has been made in all project output areas. There is a clear picture of the distribution of P and K reserves across the main cropping soils and regions of the northern grain region (NGR), and so the project team is in a position to be able to better focus research in regions where continued negative nutrient budgets will have the greatest impact on productivity. There is also increasing confidence in the ability of the Bureau of Sugar Experiment Stations phosphorous (BSES-P) and tetraphenyl borate potassium (TB-K) soil tests to quantify potential slow release mineral reserves of each nutrient. Further, prototype methods have been developed 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.

Significant advances have been made 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 cereal and pulse species on these soils is needed. The situation with cotton is much less clear, driven by the apparent inability of this species to effectively use 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.

There are now 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. 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 and volume of nutrient enrichment and the residual value of applied nutrient, are key areas for further exploration.

Recommendations

1. 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.
2. 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.
3. 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 the phosphorous buffering index (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.

4. 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.
5. 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.
6. 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.
7. 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.

Outcomes

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 nitrogen (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 is 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. Individual crop yield increases of 10-70% have been recorded in response to additional fertiliser applications 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. It has also been shown that the residual value of deep P applications is excellent, with responses recorded in over 5-6 consecutive crop seasons. Effective P application strategies have been demonstrated in terms of placement and band spacing, although at this stage rate-response functions have not been developed 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. It has been shown that the soil K requirement for cotton is two to three times as great as for grain crops in lighter soils, but the project team is 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. The field and glasshouse experiments have shown poor ability of cotton crops to effectively access banded P and K fertilisers. The project team has developed mechanised harvesting capability and the capacity to process large whole plant samples to measure fertiliser nutrient recovery, so are well positioned to undertake more detailed investigations in this system.

Achievement/Benefit

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 and cotton growing soils of the northern region.

An extensive soil sampling and laboratory analysis campaign was undertaken, using both resources in this project and also by adding value to sampling campaigns undertaken in other research projects (e.g. Land and Water Australia (L&WA) Healthy Soils, and the Soil Carbon Research Program (SCaRP)), or by agricultural consultants and regional soil surveying teams (the latter in north west New South Wales (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 more than 800 locations, including approx. 100 trial sites from the current and previous GRDC-funded nutrient projects. In summary, there are some clear trends that emerge from these analyses: (a) 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 (e.g. The Central Highlands of Queensland (QLD), northern Darling Downs, north east (NE) slopes in NSW) where K reserves are minimal, and; (b) The occurrence of P reserves is patchy, and probably linked to geology and 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 BSES-P and TB-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 faba bean has been produced, 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:

1. 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 (that is, between crops). The contribution of these slowly soluble P forms is particularly relevant in the larger soil volumes associated with subsoil root exploration.
2. 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.
3. A combination of the ratio of BSES P:Colwell P and the ratio of P released to an iron oxide (FeO) strip (or possibly a diffusive gradients in thin-films (DGT) device): BSES P may offer more broadly applicable diagnostic value.
4. 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.
5. A two-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.
6. 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 southern Queensland farming systems (SQFS) subproject (CSA00013) and 16 newly established field trials, collectively representing 44 crop-years. These comprise 12 cotton crops (five irrigated and seven dryland), 12 sorghum crops, 13 wheat crops, five pulses and two 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-K 1h 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 (that is, below the 20-30cm of planted bed/ridge) 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). This confounding has clouded the interpretation of results somewhat, but the project team has been able to devise broad soil test-crop response guidelines for P and K for grains (listed in the GRDC Update paper by Guppy et al. 2012) but not yet for cotton.

The cotton situation seems much more complex than for grains, as although many of our trial sites have shown limited or no yield response to applied nutrient, they have also shown no evidence of uptake of applied P or K in crop biomass. As a result, the lack of yield responses may be due to either (a) soil P or K status that is currently adequate, or (b) cotton crops are inefficient at accessing band-applied P or K, and so any underlying deficiencies have not been overcome by the treatments. At this stage, a combination of both is suspected, with the situation further complicated by differences in soil type that affect diffusive supply as well as cation activity ratios in the soil solution. The glasshouse P trials (see McLaren et al.) have suggested that cotton appears to be less efficient at utilising applied P fertiliser, especially when applied in bands. This seems consistent with an apparent lower soil P requirement for cotton than grains, but these observations then question the effectiveness of the main P application strategy (banded P fertilisers) used in the industry. Conversely, while the glasshouse K trials suggested similar recoveries from banded or dispersed K in cotton (but not maize, where recovery of banded K was relatively poor), acquisition of applied K was much poorer in cotton. This is inconsistent with the apparently higher K requirement for cotton than grain and pulse crops recorded in the long term K field trial. Further detailed studies on cotton responses to P and K fertilisers in soils with different background cation ratios, soil structural properties and mycorrhizal colonization will be required before more confident soil test diagnostics can be developed to indicate the need for P and K fertilisers for cotton on clay soils.

Output 3: Determine the most effective P and K fertiliser application strategies (form, placement and timing) in soils with low background nutrient status, including the residual value of those nutrients for subsequent crops.

The work addressing this output has primarily been conducted in field trials, supplemented by a small glasshouse study to look at co-location of different nutrients (N, P, K and S). Initial studies focussed on horizontal and vertical placement options for P and K fertiliser bands, with between-band spacing ranging between 100cm and 25cm, and those bands placed either deep (18-25cm), shallow (5-10cm) or a combination of both. The general lack of response to P, K or S recorded in any of the field cotton experiments conducted to date, and the lack of evidence of nutrient acquisition by the crop from those fertiliser treatments, has limited the conclusions that can be drawn for this crop. However, it is considered that there are fundamental reasons relating to cotton root distribution and cation uptake characteristics that are responsible for these results rather than any shortcomings of experimental design or seasonal effects. The grains experiments have clearly shown that to maximise crop access, a sufficient volume of soil in contact with active roots must be enriched with P or K. In the case of P, this can be achieved by fertiliser bands no further apart than 50cm. The optimal distribution between shallow and deep placement depends on the existing P status of the topsoil, the degree of nutrient stratification evident and the seasonal moisture availability. Dry seasonal conditions maximized reliance on deep bands and poor recovery from shallow P bands was recorded. Seasons with adequate in-season rainfall allowed better recovery of shallow P applications, with best recovery from combined shallow and deep bands, but when conditions were very wet, deep bands made a minimal contribution to crop P uptake.

Fewer sites have been established with K, but those sites have been based on a similar design (band spacing and position), with similar trends observed in band spacing effects on plant K acquisition (that is, bands should be less than 50cm apart). In the case of both P and K, emphasis was on developing guidelines for effective placement strategies rather than on optimising application rates, with high rates (e.g. 40kg P/ha and 100kg K/ha) typically used to ensure residual effects of applied fertiliser could be assessed. The longest running P trials have shown strong residual benefits in at least three to four crops after application, while one site is continuing to shown responses after six years and seven crops. Such sites are essential in understanding the true costs and benefits of deep placement of immobile nutrients like P and K.

One issue that complicated the study of deep placement response was the frequent encountering of concurrent or multiple nutrient limitations on crop performance. Again the most extensive evidence is in grain crops, with the response to overcoming a P limitation often then constrained by a secondary limit to potential yields (N or S or K, or in some cases all of these). There have been instances where responses to deep P have been negated unless K or S have also been applied, or the increased yield potential due to overcoming these constraints has then been limited by N availability (i.e. N rates have not been adjusted upwards to meet the higher yield targets). The latter occurrence was common in sites experiencing flooding in November 2010 and December 2011. A number of trials were established where the interactions between P, K and S were explored using factorial combinations of individual nutrient addition, with the frequency of responses being P>S>K. There were often additive effects of P and S applications, with yield response typically 15-25% and as high as 70% above commercial practice, but the additional benefit from K addition was variable and sometimes negative - possibly due to undesirable soil solution chemistry in the PKS fertiliser band reducing subsequent root access.

Preliminary studies were conducted on the effects of rate and fertiliser component mix in bands in a glasshouse trial, with evidence suggesting that addition of small amounts of N and P to K fertiliser bands can promote root activity and K uptake in maize but not in cotton. When high rates of P, K and S are combined in bands, root activity can be constrained and plant growth can be depressed as a consequence of osmotic and nutrient imbalance effects. The effects were most pronounced in cotton on light-medium clays, where plants actually died when exposed to high rates of banded P, K and S. Given the focus on infrequent tillage events for deep placement to conserve water and stubble cover, and the frequent co-occurrence of multiple nutrient limitations, further work in this area is needed to develop practical management practices.

Other Research

1. A subsequent project in the More Profit from Crop Nutrition II (MPCN II) initiative (UQ00063) and another funded by the Cotton Research and Development Corporation (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 two-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 Australasian Soil and Plant Analysis Council (ASPAC) suite of certified diagnostic soil tests.
2. 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 the 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.
3. 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. The project team has 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.

Additional Information

TI McLaren, MJ Bell, IJ Rochester, CN Guppy, MK Tighe, RJ Flavel (2013). Growth and P uptake of faba bean and cotton are related to Colwell-P concentrations in the subsoil of Vertosols. Crop and Pasture Science http://dx.doi.org/10.1071/CP13025.

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