Increasing complexity in nutrient management on clay soils in the northern grain belt – nutrient stratification and multiple nutrient limitations

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Abstract
The clay soils of the northern grains region have been viewed as highly fertile soils with significant intrinsic nutrient reserves. However, continuous negative nutrient budgets and declining soil organic matter have eroded those reserves such that successful crop production is increasingly reliant on high analysis fertilizers. Until recently fertilizer use was dominated by N inputs, with P and possibly Zn applied as starter fertilizers in the seeding trench at planting – often with rates of P application still much less than rates of crop removal. There is increasing evidence of yield constraints due to concurrent deficiencies of P, K and S, with soil tests indicating the most severe depletion of reserves of P and K occurring in the layers immediately below the top 10cm of the soil profile (ie.10-30cm). These layers are important for nutrient supply when topsoil root activity is limited by dry conditions but crop growth continues, utilizing subsoil moisture (and nutrient) reserves.

Research reported in this study clearly shows there are substantial yield responses to P fertilizers in addition to that from starter P applications, with the latter typically providing 25% or less of the potential yield increase to added P. Early results have also shown additive effects of K and/or S with P that further raise potential yields and water use efficiency, but also N demand. In some cases these limitations are at least as severe as that of P and responses to P addition are negligible unless these other constraints are also addressed. Findings suggest changes to nutrient management practices may produce major productivity gains in parts of the northern grains region.

Key Words phosphorus, potassium, sulfur, interactions, grain crops, deep placement

Introduction

The northern grains region occupies approximately 4M ha across northern NSW, southern and central Queensland. The cropping system is dominated by winter and summer cereals (wheat, sorghum and barley) with a relatively low frequency of grain legumes (chickpeas, and to a lesser extent mungbeans). The main cropping soils are Vertosols, Chromosols and Sodosols (Isbell 1996). Intrinsic soil fertility was high, especially on the Vertosols, but this has declined over time such that a significant proportion of the crop nitrogen (N) requirement is now supplied by fertilisers (Dalal and Probert 1997). There is widespread use of starter phosphorus (P) and zinc (Zn) fertiliser, while continued nutrient removal in grain is expected to increase incidence of deficiencies of other nutrients like potassium (K) and sulfur (S). Indeed, negative nutrient budgets continue to be recorded across the region. A recent assessment of the decline in reserves across the Qld cropping belt (Bell *et al*., 2010) has shown that cropped soils across all regions contained only 60% ($\pm$5%) of the organic C, 48% ($\pm$6%) of total organic N, 36% ($\pm$5%) of the particulate organic N, 68% ($\pm$14%) of the total inorganic P and 55% ($\pm$5%) of the exchangeable K reserves of adjacent uncropped reference sites. This depletion is resulting in increasingly complex nutrient management decisions for growers, with a recent survey of grain nutrient concentrations in wheat (M Bell, K Klepper and D Lester, unpub. data) suggesting significant proportions of the commercial grain crop was indicative of low-marginal status of one or more of N, P, K and S.

The commercial response to this decline in intrinsic fertility reserves is complicated by a number of factors including uncertainty in soil test indicators of available reserves of nutrients like P, K and S on these soil types, the relative importance of subsoil (>10cm) reserves of nutrients (other than N) to crop nutrient acquisition and yield (and hence the need for soil tests in these deeper layers), and finally seasonal variability in productivity and financial returns. The ability of these clay soils (especially the Vertosols) to accumulate significant reserves of plant available water during fallow periods (150-250mm), and the less reliable occurrence of in-season rainfall means crops are dependent on access to subsoil water and nutrients to achieve reasonable productivity. Norrish (2003) and Wang *et al*. (2007) were able to show obvious depletion of labile P in subsoils (10-60cm) of rainfed cropping soils in NW NSW and the Darling Downs in Qld, while Singh *et al*. (2005) showed significant improvements in yield and crop P status by placing P fertilizers deeper in the soil profile (ie. 15-25cm). The extent and severity of subsoil P deficiency, the degree to which this interacts with declining reserves of other nutrients (e.g., low reserves or K and or S, as suggested by soil test results in Table 1) and the likely quantum of yield response to overcoming these constraints further complicate fertilizer decisions.

This paper reports the results of a series of experiments exploring the impact of overcoming low subsoil P status, and the interactive effects of P, K and S limitations recorded across the northern grains region.

Methods

Site selection and soil analytical methods

Sites were chosen on the basis of soil test results, with an initial focus on available P in the subsoil (10-30cm) but subsequently growing interest in the combined P, K and S status in both topsoil and subsoil layers. Sites in the experimental program were located across a broad 1000km N-S transect of the northern grains region, from the Liverpool Plains in NSW to the northern highlands of Central Qld. All trials were on commercial properties growing irrigated or dryland cotton and/or grains, although the studies reported in this paper were dryland grains producers from southern and central Qld (Table 1).

Soil samples were analysed using standard methodology listed in Rayment and Lyons (2011). Soil pH was determined in 1:5 soil:water; plant available P using 0.5M $NaHCO_3$ and 0.005M H_2SO_4 (Colwell P: Method 9B2 and BSES P: Method 9G2, respectively); exchangeable cations and CEC were determined using 1M NH_4Cl at pH 7 (Method 15A1) while SO_4-S was determined by extraction with KCl (KCl40 - Method 10D1).

Fertilizer treatments and application methods

Different trial designs were used at these sites, and in the case of Brookstead, Capella and Jandowae, multiple trials were established in different seasons. Details are as follows –

<u>Responses to P</u> – split plot trials were established at Wondalli (March 2008), Jandowae (March 2009) and Capella (November 2007) to investigate P responses in addition to traditional starter P applications. Main plots consisted of starter P applications of either 0P (all sites), 5-6 kg P/ha as mono-ammonium phosphate (MAP, all sites) and 10 kg P/ha as MAP (Capella). Main plots were split to different additional P applications, applied from 3-8 months prior to crop establishment. These subplot treatments consisted of applications of triple superphosphate (TSP) to supply 45 kg P/ha in bands 100cm apart (all sites) or 50cm apart (Wondalli and Jandowae), applied to either the top soil (~7.5cm) or the subsoil (20-25cm). There were additional treatments where the same rate of P was applied to the soil surface and incorporated at planting, and where TSP was applied at the same rate in each position (ie. a high P treatment applying TSP at the surface, shallow and deep positions to provide a total of 135 kg P/ha applied). Crop responses were assessed in the initial crop (wheat at Jandowae and sorghum at Capella and Wondalli), and in subsequent crops in the rotation until after the 2010/11 (Capella), 2011 winter (Wondalli) or 2011/12 summer (Jandowae) crop seasons to assess residual value. Differential starter P applications (treatment main effects) were maintained for each crop over the experimental period. Both Wondalli (wheat) and Jandowae (chickpea) sites had crops lost in the 2010 winter season due to flooding near harvest.

<u>Interacting effects of P, K and S</u> – Factorial experiments were established at Brookstead and Kupunn in autumn 2010 to explore the interacting effects of improved soil P, K and S status in raising yield potentials above commercial practice (typically preplant N and starter P). Additional P (40 kg P/ha), K (200 kg K/ha) and S (88 kg S/ha) were applied alone or in combination, in bands 25cm apart and split between shallow (~7.5cm) and deep (~20cm) placement. The products used were MAP (to supply P), ammonium thiosulfate (ATS, to supply S) and muriate of potash (MOP, to supply K) where products were applied alone, while sulfate of potash (SOP) was combined with ATS in the KS treatment. Urea was used to equilibrate N inputs. The Kupunn site experienced a crop failure in the year of trial establishment, with the cotton crop severely damaged by flooding. This site was fallowed through to sorghum in the 2011/12 summer.

Another trial was established at the Capella site to compare addition of a compound NPKS fertilizer applied at 140 kg/ha at planting, split between the planting row and the middle of the 100cm inter-space at `10cm depth, with the traditional approach using preplant urea and starter P applied as MAP. The compound fertilizer supplied an additional 8 kg N/ha, 15 kg P/ha, 14 kg K/ha and 15 kg S/ha, and the treatments were compared in commercial scale strips with 6 replications.

Results and Discussion

Data are presented for soils from the five sites discussed in this paper, with the soils characterised by generally neutral-strongly alkaline pH_w, low Colwell and BSES P (especially in the subsoil), moderate to high cation exchange capacities (CEC) and moderate-low exchangeable K and SO_4-S (with the exception of the site at Wondalli). All soils were classified as Black and Grey Vertosols and were characterised by low Phosphorus Buffer Indices (PBI) of 80-120.

Responses to P

Responses to P fertilizer were recorded at the Wondalli and Jandowae sites in both the year of application and in crops grown some 2.5 years later (Table 2), but there were surprisingly (given the low soil P status in Table 1) no P responses recorded at Capella over a similar interval (data not shown). When the only P applied was as starter fertilizer, responses were statistically significant only in the high yielding Jandowae sorghum crop in 2011/12 (8% yield increase). There were suggestions of similar magnitude responses in both years at Wondalli (7% and 10% yield increases with starter P, respectively), although these differences were not statistically significant. All three crops experienced above-average growing season rainfall. In contrast, there was no suggestion of a starter P response in the very dry 2009 wheat crop at Jandowae.

Table 1. A subset of soil analytical data to characterise the trial sites discussed in this paper.

		pH_w	Colwell P	BSES P	ECEC	Exch K	SO_4-S
			(mg/kg)		(cmol/kg)		(mg/kg)
Brookstead	0-10cm	5.8	32	34	21.4	0.6	9
	10-30cm	7.3	1	5	27.8	0.3	5
Jandowae	0-10cm	7.0	13	22	25.5	0.5	4
	10-30cm	7.8	4	12	31.5	0.2	3
Wondalli	0-10cm	9.0	8	14	36.9	1.2	6
	10-30cm	8.9	5	8	35.9	0.8	16
Kupunn	0-10cm	8.0	12	25	27.6	0.8	NA
	10-30cm	8.6	2	13	29.2	0.5	NA
Capella	0-10cm	7.8	7	10	69.2	0.3	3
	10-30cm	8.2	5	6	68.7	0.1	3

Both the Wondalli and Jandowae sites recorded significant yield increases in both crop seasons to extra P applied prior to the initial crop. Using the High P treatments with starter P as an indicator of the P-unlimited yields in each crop-site combination, total response to P fertilizer was 31% and 36% at Wondalli and 22% and 36% at Jandowae in the first and second crops, respectively. Using starter P only (standard industry practice) produced yields that were consistently ~20% less than yields where P limitations were removed. The prolonged response to P added 2.5-3 years earlier was testament to the strong residual value of fertilizer P in these soils with low PBI. Residual effects of applied P are still being recorded 6 crops/5 years after deep applications of P in an on-farm strip trial at Brookstead, and averaging 15% above commercial practice (with starter P only).

Table 2. Grain yield (kg/ha) responses to starter P in the seeding trench and to additional shallow (banded or mixed) or deep (banded only) P applications made 6-8 months prior to the initial crop at two sites in southern Qld.

Starter P	Extra P	Wondalli		Jandowae	
		Sorghum 2008/09	Wheat 2011	Wheat 2009	Sorghum 2011/12
No starter P	Nil	3750	3650	2100	7710
	45P Shallow bands	4170	4340	2290	8780
	45P Deep bands	4180	4390	2490	10120
	45P Surface mixed	3800	3850	2010	9720
	High P	NA	NA	2380	9740
Starter P applied	Nil	4010	4020	2020	8350
	45P Shallow bands	4410	4510	2280	9370
	45P Deep bands	4130	4630	2330	9520
	45P Surface mixed	4250	4340	1860	9180
	High P	4910	4940	2560	10490
lsd (0.05)		580	600	280	490

In these studies there was no consistent benefit from placing additional P bands at 20cm compared to 7.5cm, although this may have been a function of the wetter than average seasonal conditions in 3 of the 4 seasons reported here. The exception was the 2009 wheat crop at Jandowae, where there was a trend for deeper P placement to give the biggest yield response (i.e., 1935 v's 2285 v's 2410 kg/ha in the surface, shallow and deep treatments, respectively). Data from other studies (Bell and Lester, unpublished data) suggest that response to deep P applications are greatest when bands are 25-50cm apart, so the 100cm band spacing used exclusively at Capella, and in half the treatments at the other sites, may have limited potential responses.

Interactive responses to combinations of P, K and S

The experiments at Brookstead and Kupunn both recorded significant yield increases relative to the control (Farmer reference) treatment. At the Brookstead site responses to both P and S were recorded individually, but not to K, and additive effects of P and S yielded 50% higher than the standard practice. At Kupunn there was a strong P response and a lesser response to K, but there was no evidence of additivity until all three nutrients were there together. In this case, combined P, K and S addition yielded 26% more than the standard practice.

It is interesting to contrast the effects of combined P, K and S addition at the two sites. At Brookstead, most of the yield advantages of P and S were lost when K was added to the bands – possibly due to salt effects in the band reducing access to the nutrients in critical stages of crop growth. The opposite occurred at Kupunn, although at this site the crop was encountering bands that were laid down some 18 months previously and a flooded cotton crop beforehand. In this case, residual hostile conditions in the fertilizer bands would have been unlikely.

Table 3. Interactive effects of P, K and S fertilizers on sorghum yield (kg/ha) at Brookstead and Kupunn

Brookstead		Kupunn	
Treatments	Sorghum 2010/11	Treatments	Sorghum 2011/12
Control (starter P)	4240	Control (starter P)	6220
Extra P	5520	Extra P	7300
Extra K	4530	Extra K	6870
Extra S	5520	Extra S	6450
Extra P and K	NA	Extra P and K	7350
Extra P and S	6380	Extra P and S	7240
Extra P, K and S	4700	Extra P, K and S	7830
LSD (0.05)	740	LSD (0.05)	550

The experience at Capella, although less definitive, also supported the existence of interactive effects of P, K and S. In fields where effects of P addition were consistently non-significant when added as starter P or additional bands, sorghum yields were increased significantly (from 1680 to 2190 kg/ha, or a 30% increase) by the addition of the compound NPKS product, compared to the traditional starter P alone. Other replicated strip trials conducted at Clermont and Capella by Pacific Seeds (T. Philp, pers. comm.) showed even greater responses in the same season, with 44% yield increases by the addition of P, K and S in combination. Interestingly, the vast majority of that response was only recorded once S was added to the program.

Conclusion

This research is clearly indicating that crop yields and water use efficiency in parts of the northern grains region are being increasingly constrained by nutrient limitations other than N. In the case of P, current traditional approaches to P application (i.e., starter applications in the seeding trench) are inadequate to overcome limitations when soil P reserves are limited. There is still considerable uncertainty about the ability of soil tests to accurately predict responsiveness to P, K and S fertilizers, and in the case of K, the most effective application strategy to ensure crop uptake.

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