Increasing grain yields in the sub-tropics by deep banding phosphorus

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Abstract

Soil testing has shown some common vertosol cropping soils across Central Queensland (CQ) have developed a nutrient stratification pattern in relation to non-mobile nutrients such as phosphorus (P) and potassium (K). These soils can be chronically low in P in both surface (0 -10 cm) and sub-surface (10 – 30 cm) layers but nearly all are showing P concentrations < 5 mg/kg in the sub-surface layers. The importance of low sub-surface P concentrations on the efficiency of plant P uptake and grain yield were uncertain.

A series of trials were established across CQ cropping area from 2013 to 2015, to investigate whether applying P fertilisers in the sub-surface layer would improve plant access to P and improve grain yield. Sites were selected on the basis of Colwell P being < 8 mg/kg in the 10-30cm layer. Several rates of P were applied through a ripper bar using mono ammonium phosphate (MAP) granular fertiliser banded at 20 - 25 cm deep on 50 cm band spacings.

Monitoring crop performance across the rotation sequence at each trial site showed 80 % of the crops recorded 10 - 100 % increases in grain yield to rates of 20 kg P/ha and 40 kg P/ha, with a large proportion averaging increases of 15 % to 25 %. Residual benefits have been recorded in five consecutive crops since the initial treatments were applied.

These trials have proved that access to sub-surface P is important for efficient uptake of P and ensuring water limited yield potential. Given that crops are largely grown on soil moisture stored from a defined summer wet season, subsoil P availability is a critical success factor for CQ farming systems.

Keywords

stratification, nutrients, vertosols, soil moisture, sub-surface, fertilizer

Introduction

Phosphorus is a critical element for plant growth, with many key metabolic functions such as photosynthesis and cell division requiring a small but consistent supply of phosphorus throughout the life of the crop (Raven & Johnson 1989). The supply of phosphorus through soil solution and into plant roots can be a complex one given that P is not mobile in clay soils (Glendinning 1990), but managing this complexity is a key factor for sustainable cropping systems.

In the sub-tropics of Queensland many broadacre crops are grown on stored moisture, as most of the annual rainfall occurs between January and March. Limited in crop rainfall means most grain crops are flowering and filling grain while relying on sub-surface moisture (10 – 90 cm) and this means that nutrients are also being taken from this zone. In a zero-tillage system, stubble is breaking down and returning nutrients to the surface of the soil, but nutrients such as P and K will not leach through a vertosol soil (Bordoli and Mallarino, 1998) and so become concentrated in the top 5 cm of the soil profile.

This stratification of nutrients has shown up regularly in soil tests across cropping soils in CQ and has been one of the main reasons that a series of experiments have been undertaken across CQ to investigate whether this stratification is an impediment to grain production. The objective of this study is to test whether the application of P based fertiliser banded into the sub-surface layer (10 – 30 cm) will improve grain yield.

Methods

A total of 10 sites were established in commercial fields across CQ based on soil testing data that showed low Colwell P in either the surface layer (0 -10 cm) or the sub-surface layer (10 – 30 cm) or a combination of both. This paper will examine a consistent set of five trial sites where the experiments were conducted with the same set of treatments.

These five sites will be referred to in this paper based on the closest local township name or the name of the district where the trial was located. Sites are listed below along with the year that the deep P treatments were established.

1. Dysart - established August 2013
2. Clermont – established in October 2015
3. Dululu – established in November 2015
4. Kilcummin – established in March 2015
5. Comet River – established in December 2015

Deep banding was conducted using a two-metre wide Yeomans™ ripper bar set up to apply fertiliser on 50 cm band spacings. Background nutrition was applied at the same time as the P bands to offset any other nutrient variables and N inputs from different P rates were equilibrated with urea. The non-mobile nutrients P and K were placed at a depth of 20 – 25 cm in one boot, while the N and S were applied at 10 – 15 cm through a separate boot. Basal Zn was applied via a liquid injection outlet positioned 5 cm above the N and S band.

Five rate-based treatments were common across all sites and the rates of nutrient applied in those treatments are summarised in Table 1. These five treatments were replicated across all five sites, with between four and six replicates of each treatment. The 'FR' label represents farmer reference, which is essentially a 'local practice' benchmark for each site. The FR plots had no deep fertiliser applied and were not ripped, so they represent the original paddock performance and only received what was applied by the farm co-operator at the time of planting.

The treatment labels in Table 1 will be used throughout the rest of the paper and is focused on the response to deep P only, rather than effects of tillage or the other background nutrients. Plot sizes varied depending on the farming system that existed at each site and P bands were only applied once, then subsequent crop performance was monitored over time. Seasonal crop inputs, sowing and site management were conducted by the local co-operator, and yields were obtained using a small plot harvester.

Table 1. Rates of nutrient applied across the common treatments used in each trial site.

Trial	Treatment Label	N rate (kg/ha)	P rate (kg/ha)	K rate (kg/ha)	S rate (kg/ha)	Zn rate (kg/ha)
Phosphorus	0P	80	0	50	20	0.5
	10P	80	10	50	20	0.5
	20P	80	20	50	20	0.5
	40P	80	40	50	20	0.5
	FR	0	0	0	0	0

Results

The mean grain yield data from 14 crop years shows several different levels of response to the different rates of deep P applied (Table 2 and 3). Despite the variability in the data, the response to deep P is significant in 11 out of the 14 cropping years shown in the tables which is a response rate of ~80%. The differences in mean grain yields between the 0 and 40 rates of P can be as little as 17 kg/ha or as much as 975 kg/ha. This variability can be attributed to changing seasonal factors mostly related to soil water and in-crop rainfall, however the distribution of P in the soil profile can interact with these seasonal factors to influence the size of the yield response to deep P.

For example, the wheat crop at the Dululu site in 2016, that did not respond to deep P treatments, was related to relatively high amounts of in-crop rainfall, rewetting the surface soil regularly and allowing the plant to access the reasonable levels of P in the surface soil (0-10cm), that was a characteristic of this site. Alternatively, the non-response in wheat at the Comet River site (2017) was related to water limited conditions where the plants only had a primary root system to access the deep bands for a limited amount of time and the plants were drought stressed for most of the season.

Table 2. Mean grain yields (t/ha) in response to increasing P rates applied in deep placed bands in trials at Dululu, Clermont and Kilcummin.

Deep P rate (kg/ha)	Dululu trial site			Clermont trial site		Kilcummin trial site
	2016 wheat	2017 chickpeas	2018 mungbeans	2016 sorghum	2018 chickpea	2015 chickpea
FR	3.858^{ns}	2.686d	0.721^{ns}	1.628a	0.33a	1.833a
0P	4.092^{ns}	2.922c	0.868^{ns}	1.942b	0.321a	1.841a
10P	4.095^{ns}	3.096b	0.839^{ns}	2.371c	0.79b	2.243b
20P	4.126^{ns}	3.221ab	0.844^{ns}	2.317c	0.976c	2.345bc
40P	4.109^{ns}	3.348a	0.858^{ns}	2.701d	1.296e	2.394c

^{ns} no significant difference at 95% level; different letters mean significant differences in the yield.

Table 3. Mean grain yields (t/ha) in response to increasing P rates applied in deep placed bands in trials at Dysart and Comet River.

Deep P rate (kg/ha)	Dysart trial site					Comet River trial site		
	2014 sorghum	2015 sorghum	2016 sorghum	2017 chickpea	2018 sorghum	2016 chickpea	2017 wheat	2018 chickpea
FR	2.285a	2.657a	1.855a	0.538ab	2.349a	1.623c	0.678^{ns}	1.376d
0P	2.739b	2.985bc	2.196b	0.709b	2.817b	2.03b	1.117^{ns}	1.445cd
10P	3.175c	3.221de	2.353bc	0.959c	3.349c	2.041b	1.144^{ns}	1.706ab
20P	3.31cd	3.395e	2.525c	1.172cd	3.548cd	2.425a	1.237^{ns}	1.647abc
40P	3.452d	3.258de	2.291c	1.415d	3.788d	2.522a	1.241^{ns}	1.771a

^{ns} no significant difference at 95% level; different letters mean significant differences in the yield.

On the extreme end of the relative response results were two chickpea crops that were grown on limited in-crop rainfall at the Dysart site in 2017 (Table 3) and at the Clermont site in 2018 (Table 2). The relative responses (Figure 1) to 40 kg P/ha applied were 100 % at the Dysart site (2017 Chickpea) and 300 % at the Clermont site (2018 Chickpea).

Both crops grew with limited effective in-crop rainfall (35 mm for Dysart, 8 mm for Clermont) but had reasonable stored moisture profiles. In effect, both crops would have had limited access to the top 10cm of soil profile, which is where the greatest soil P concentrations were typically found.

The zero P plots at these sites grew 709 kg/ha and 321 kg/ha of grain yield, respectively, and did not differ to the crops grown under the FR management treatment. The subsequent yield responses meant the deep P application at the highest rate (40 kg P/ha) effectively doubled the yield at the Dysart site (1,408 kg/ha) and quadrupled the yield at the Clermont site (1,298 kg/ha). Further to this, the Dysart chickpea crop was the fourth crop to be grown on the site since the original application of deep P.

Data also suggests that residual benefits from single deep banded P applications are strong, with continued significant grain yield responses to the application of deep P up to five years after the deep banded treatments were applied (Dysart site).

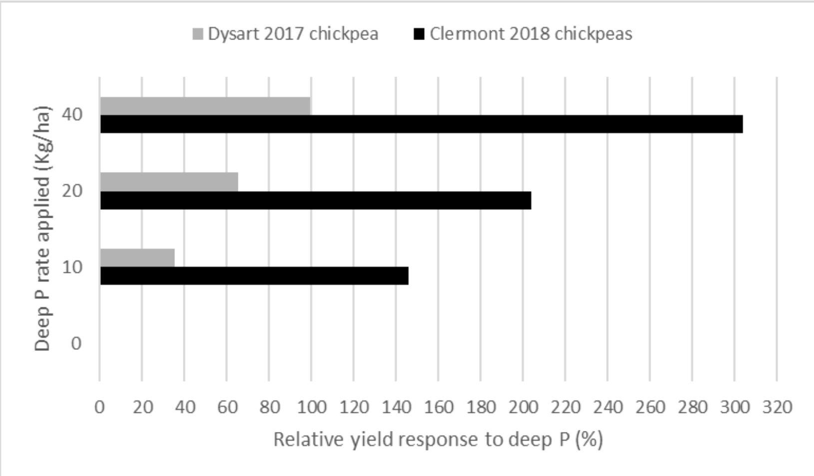

Figure 1. Relative grain yield responses to deep applied P treatments as a % of the zero P treatment for two chickpea crops that were grown with limited in-crop rainfall. Both these crops were also grown on sites that had limited surface (< 8 mg/kg) and sub-surface (< 3 mg/kg) Colwell P concentrations.

The difference in grain yields between 20 kg P/ha and 40 kg P/ha rates was negligible in most situations, although there were indications that in later years the yields were starting to diverge in favour of the higher rate (Dysart site) or in very dry conditions, the higher rate has an advantage (Clermont site).
The variability in the response to deep P requires more detailed analysis of this trial data, including P uptake in plant and grain tissue and an assessment of other potential yield constraints. Early indicators would suggest that there is no single factor that drives most of this variability but more a combination of factors such as P distribution in the surface and sub-surface layers, planting depth, timing and amount of in-crop rainfall and the root distribution of the crop species.

Conclusion

The placement of bands of P fertiliser at 20 cm to 25cm deep in the profile is an effective strategy for increasing grain yields in cracking vertosol soils that have been assessed as having a low P status (< 8 mg/kg Colwell P).

These findings have major implications for zero till farming systems based in the sub-tropics. The erratic in-season rainfall and the reliance on stored soil moisture means that P supply from surface soils is often limited and sub-surface supply of P is being depleted and not replaced.

References

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