Deep P bands – the solution to subsoil decline or just a useful supplement?

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Abstract

Increasing removal of phosphorous (P) via grain harvests, shallow fertiliser placement and direct drill tillage systems have collectively produced soil P profile distributions that are strongly stratified and increasingly deficient in subsurface layers. Nutrient supply in these layers is a critical success factor for cropping systems that rely on stored soil moisture. Banding of P fertilisers into the 10-30cm profile layer has produced strong crop yield responses in Vertosols in CQld, particularly in seasons where topsoils are dry for extended periods. The relationship between P uptake and grain yield is typically linear, with little evidence of luxury P accumulation in either biomass or grains. We hypothesize that root proliferation around deep P bands rapidly dries these P-rich zones and limits P acquisition unless rain events are large enough to rewet those profile layers. While residual fertiliser benefits are strong, crops are still reliant on declining indigenous P reserves to achieve water-limited yield potential.

Keywords

Phosphorus, deep-banding, crop uptake, rainfed cropping, Vertosols.

Introduction

The broad acre cropping regions in Queensland are dominated by Vertosols and Sodosols (Webb et al. 1997), with the moderate to high water holding capacity of these soils a critical factor for cropping success. Tillage systems are predominantly minimum or no-till, with an emphasis on retaining residue cover to maximize infiltration and storage of rainfall during fallows between crop seasons. Variable in-season rainfall increases crop reliance on soil water stored during the fallow, but efficient use of that water is dependent on access to nutrients from deeper profile layers when the topsoil layers are dry. Mobile nutrients like nitrogen (N) will slowly leach into deeper profile layers during the refilling of profile water during a fallow, but immobile nutrients like phosphorus (P) and potassium (K) do not redistribute with infiltrating water due to a strong affinity to clay surfaces. The combination of an increasing duration of cropping, nutrient inputs well below replacement and shallow application practices have led to widespread evidence of increasingly sub-optimal P and K availability – particularly below the shallow topsoil layers. Periodic banded applications of P and K in the 10-30cm profile layer are being used to address these subsoil deficits of immobile nutrients, with growing evidence of widespread effectiveness of this strategy – especially in CQld (Bell et al. 2012, Lester et al, 2017, Sands et al. 2021).

The success of deeper banding of P fertilisers is reliant on proliferation of roots around the fertiliser bands (van der Bom et al. 2020) and an extended period of crop P access in soil layers that are wetter for longer. Crop responses to deep P bands will therefore fluctuate in response to the period that the relatively P-enriched topsoil is wet during the growing season, and the timing and extent to which the deeper bands are themselves rewet, to allow continued P acquisition. Recent studies by Meyer et al. (2020) have also suggested that the form of P fertiliser will also influence P availability, and hence crop P response. Despite this improved understanding of the mechanisms of deep P banding responses, and evidence of the cost-effective agronomic responses in many situations, the extent to which these management strategies are overcoming an increasing soil P deficit and allowing crops to achieve water limited yield potentials has not been determined. We focus on this aspect of the banding responses, using three long term experimental sites from across CQld.

Methods

Site details

The experimental sites were located in fields on commercial farms near Dysart, Clermont and Dululu in CQld that typically received annual P applications of 4-6 kg P ha^{-1} applied as starter fertiliser. Experimental designs included a replicated Farmer Reference (FR, an untilled control) treatment to benchmark current commercial cropping practice, while all other plots were ripped (to 20cm depth) with no basal nutrients, basal nutrients alone (predominantly N and K), or basal nutrients plus P applied as mono-ammonium phosphate at rates to supply 10, 20 or 40 kg P ha^{-1}. Deep P bands were applied in 2013 (Dysart) and 2015 (Clermont and Dululu), with re-applications made in late 2018 at all sites to compare P availability from the residual P from the original applications with freshly banded P. Once treatments were imposed, the field was managed according to local practice (sowing, annual fertiliser etc.) by the co-operator.

Important soil properties are shown for each site in Table 1, with variable amounts of readily available (Colwell) P in the 0-10 cm layer (5-17 mg P kg^{-1}) but uniformly very low available P in the 10-30 cm soil layer (1-3 mg P kg^{-1}). There was greater variation in the less readily available BSES P between sites, but all were considered likely to be strongly responsive to deep P bands and to show reasonable residual effects of P application (i.e. PBI was in the moderate range of 100-150).

Table 1. Soil characteristics from the sites of deep-banded P experiments.

District	Depth (cm)	pH (1:5)	Org C (%)	CEC (cmol (+) kg^{-1})	Colwell P (mg kg^{-1})	BSES P (mg kg^{-1})	PBI
Dysart	0-10	7.8	1.0	36	5	8	110
	10-30	7.9	0.9	29	1	3	150
Clermont	0-10	7.9	0.7	67	8	35	160
	10-30	7.9	0.7	68	2	25	170
Dululu	0-10	7.3	1.0	22	17	21	100
	10-30	8.6	0.6	28	3	5	110

Crop sequences varied between locations, with Dysart growing summer sorghum and winter chickpeas, Clermont sowing winter wheat and chickpeas and summer sorghum and Dululu growing winter wheat and chickpeas and summer mung beans. Sowing decisions were based on having sufficient moisture stored in the soil profile to indicate a successful crop was likely. Growing seasons varied markedly, with the winters of 2018 and 2019 proving particularly dry, with little or no effective in-crop rainfall.

Measurements

In each crop season, starting profile moisture was monitored, along with in-crop rainfall. Biomass samples were collected near to maximum biomass for that crop season, before crop senescence began. Samples were oven dried, weighed and analysed for P concentration, with data enabling growth responses to be related to crop P acquisition. Grain yields were collected by small plot harvesters, with two independent yield estimates obtained from each plot. Yields were reported at standardized moisture contents for each species, and a subsample of grain from a selected set of treatments was analysed to determine crop N status (grain protein) and grain P concentration.

Treatment effects at each site were assessed using analysis of variance, while relationships between crop P acquisition and biomass and grain yield were determined using least squares regressions.

Results and Discussion

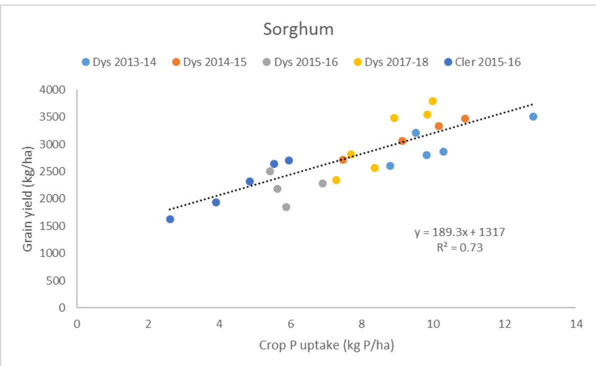
Responses to deep P treatments were significant in 10 out of the 13 crop seasons across the three experimental sites. Those site-years that did not show significant responses were due to extended access to the relatively P-rich top 10cm during a wet season (Crop 1 wheat at Dululu,), strong seasonal constraints to crop yield potential (Crop 3 mung beans at Dululu) and effects of tillage on soil moisture reserves (Crop 3 sorghum at Clermont). There were also occasional indications that the P response was being constrained by a lack of available N (Crop 3 sorghum at Dysart, where grain proteins were <8.5%). The result from the Dululu wheat crop in the wet 2016 growing season was consistent with prolonged root access to a relatively enriched top 10cm of the soil profile (Colwell P of 17 mg kg^{-1}), with crop P uptake in the FR treatment of 11 kg P ha^{-1} and no evidence of additional P uptake in response to the banded applications.

Table 2. Yields for the farmer reference treatment (Y_0) and the greatest deep P response (Y_{max}) for each site and season. Symbols (*) indicate yield increase was significant (P<0.05).

District	Crop 1#		Crop 2		Crop 3		Crop 4		Crop 5		Crop 6	
	Y_0	Y_{max}	Y_0	Y_{max}	Y_0	Y_{max}	Y_0	Y_{max}	Y_0	Y_{max}	Y_0	Y_{max}
Dysart	2.6	3.5*	2.7	3.5*	1.8	2.5*	0.4	1.4*	2.3	3.8*	1.2	3.6*
Clermont	1.6	2.7*	0.3	1.3*	1.5	1.5	-	-	-	-	-	-
Dululu	3.9	4.2	2.7	3.3*	0.7	0.9	0.4	1.3*	-	-	-	-

Crop sequences were – Sorghum-sorghum-sorghum-chickpeas-sorghum-chickpeas at Dysart; Sorghum-chickpeas-sorghum at Clermont; and Wheat-chickpea-mungbean-chickpea at Dululu.

The relationship between crop P uptake and grain yield for the most widely grown crops at these sites (summer sorghum and winter chickpeas) are shown in Figure 1. Overall crop P content in sorghum crops was generally greater than chickpeas, but within an individual growing season the net impact of deep P bands on crop P acqusition was ≤ 4 kg P ha^{-1} in sorghum but as much as 5-7 kg P ha^{-1} in chickpeas. The larger P uptake in chickpeas was predominantly in response to the re-applied P bands at the Dysart and Dululu sites in 2019, and was not tested for sorghum due to the negative impacts of tillage on soil moisture and yield potential at the Clermont site.



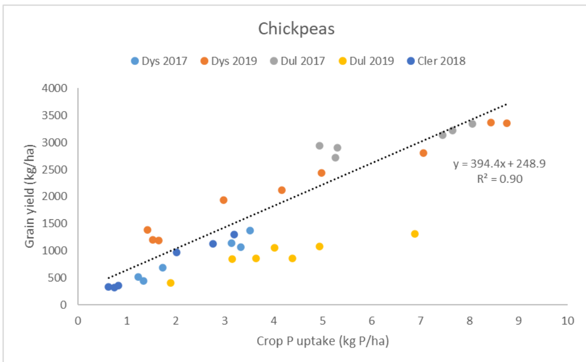


Figure 1. The relationship between P accumulation in crop biomass and grain yield for sorghum (left) and chickpea (right) crops grown across sites and seasons. The pooled regression line has been fitted to the combined data set for each crop, with the exception of the N-deficient 2015/16 sorghum crop at Dysart and the 2019 chickpea crop at Dululu, where re-application of deep P resulted in crop P acquisition well in excess of that needed to meet seasonal yield potential.

Excluding the N-deficient sorghum crop at Dysart (Crop 3), and the final chickpea crop after reapplication of deep P at Dululu (Crop 4, where yield potential was severely constrained by late season water stress), increases in crop P uptake have produced linear increases in grain yield, with an addition 390 (chickpeas) or 190 (sorghum) kg additional grain produced kg^{-1} additional P uptake. If crops were able to efficently exploit the deep P bands, curvilinear relationships between P uptake and grain yield would be expected – much like that which occurred in the chickpea crop at Dululu in 2019. This suggests that crop P acquisition was constrained under most seasonal conditions, either by a lack of root activity in the vicinity of the bands or by drying out of the band environment, both of which would have limited fertiliser P acquisition.

Conclusion

Agronomic responses to deep banded P fertiliser have been significant and profitable in most crop seasons at low P sites in CQld, with exceptions being when other nutrients constrain yield potential or when seasonal conditions limit the response to additional P uptake. In situations where topsoil P is adequate and seasonal conditions allow prolonged topsoil access and root activity (e.g. the 2016, Crop 1 growing season at Dululu), crops can acquire enough P to meet seasonal yield potential, although these situations were rare (1 of 13 site years). The strong linear relationships between crop P uptake and grain yield in responsive seasons suggests that single deep P applications are not enough to overcome strong P deficiencies at low P sites – even when applications are made at recommended depths (20cm) and band spacing (50cm). We hypothesize that root proliferation and rapid moisture depletion around P bands limits the extent to which bands can meet crop P demand. When this is combined with seasonal conditions that do not allow rewetting of the band environment during the growing season, further depletion of indigenous P or constraints to crop performance will result. These observations suggest that overcoming subsoil P depletion will represent an on-going challenge for CQld cropping systems.

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