Mixed results on grain yield responses to deep-placement of P in southern Queensland

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Abstract
Deep-placement (0.2 m) of phosphorus (P) for grain crops has produced a range of outcomes across 11 locations and 24 site years in southern Queensland. Some locations have provided substantial increases in yield over several seasons, but others fail to respond. Both summer and winter cereals appear more consistent in responding to deep P than winter pulses. There were too few summer pulses to make any conclusions about their responsiveness. Experiments used either triple superphosphate or mono-ammonium phosphate as a P source, with indications that fertiliser form may influence P response.

Keywords
Phosphorus, fertiliser, superphosphate, MAP.

Introduction
Cropping in the northern grains region occurs primarily on heavy clay soils, and is dependent on the efficient capture and storage of predominantly summer rainfall in the soil profile, for later extraction by either winter (predominantly wheat, barley and chickpea) or summer (predominantly sorghum, maize and mungbean) crops. Native soil fertility for some soil types was high (primarily the Vertosols) but this has declined over time with the change in land use to continuous cropping.

As moisture stored in the soil profile is the principal plant water source, it is not surprising that nutrient reserves throughout the soil profile are important to allow the achievement of the water-limited yield potentials. While soil sampling to determine how much fertiliser N is needed considers the whole rooting depth (0-0.9 or 1.2m, depending on site), soil nutrient sampling for the largely immobile nutrient P have traditionally focussed on the shallow surface layers (0-0.1 m) as the basis for determining the need for starter P fertiliser applications (Chisholm and Strong 1984). However, subsoil reserves of phosphorus (P) have been exploited for crop growth (Bell et al. 2012), and recent research has highlighted the importance of the 0.1-0.3 m layer for supplying crop needs of less mobile nutrients like phosphorus and potassium (Guppy et al. 2012). During earlier proof of concept research into deep-placement of nutrients, significant grain yield increases have been demonstrated (Bell et al. 2012) but this used a presence or absence model of application. This research explores the rate responses across a number of sites.

Methods
Eleven experiments were established across southern Queensland, extending from Jimbour in the east to west of Roma. All sites included an untreated control (labelled FR or “farmer reference”), representing the typical production from current practice and fertility. A contrasting selection of responses represented by four of these sites will be presented in this paper, with the respective soil types being Grey Vertosols at Lundavra, Mt Bindango and Wondalli, and a Brown Vertosol at Jimbour West.

Deep-banding was typically conducted several months prior to the next intended sowing to allow sufficient time for seed bed reconsolidation. Bands were applied at ≈ 0.2± 0.05 m depth on 0.5 m row spacing using a 75 x 25 mm shank, with site and management details and P rates shown in Table 1. Background applications of sulfur (S, applied as ammonium sulfate), zinc (Zn) and N (as urea) were made to reduce potential nutrient constraints and, in the case of urea, to equalise treatment N inputs. The urea was applied in a mid-row band between the P fertiliser bands, but Zn and S were injected into the P band. There were six replicates at all sites.

Sowing and other agronomic practices were conducted by the farmer co-operator using the same management as in the rest of the field. At physiological maturity, biomass cuts from selected treatments were collected to quantify crop growth and nutrient uptake. Biomass cuts were dried at 65 °C, weighed, mulched and finely ground. Samples were digested prior to nutrient analysis using ICP. Grain harvest was undertaken using a plot harvester, with grain yield corrected to the relevant moisture standard for receival into storage.

Table 1. Experimental details for selected deep-placed P sites in Southern Queensland.

Site **Location**	**Lundavra** **28.0°S; 150.0°E**	**Wondalli** **28.5°S; 150.6°E**	**Jimbour West** **26.9°S; 151.1°E**	**Mt Bindango** **26.5°S; 148.6°E**
Deep P application	Dec 2012	May 2013	Jan 2014	Dec 2015
P Product	Triple superphosphate (TSP)	Mono-ammonium phosphate (MAP)	Mono-ammonium phosphate (MAP)	Mono-ammonium phosphate (MAP)
P rates (kg P/ha)	FR, 0, 0, 5, 10, 20, 40, 80	FR, 0, 0, 0, 10, 20, 30, 60	FR, 0, 0, 0, 10, 20, 30, 60	FR, 0, 0, 10, 20, 30, 40, 60
Basal nutrients	40 kg N/ha 10 kg S/ha 0.5 kg Zn/ha	40 kg N/ha 10 kg S/ha 0.5 kg Zn/ha	60 kg N/ha 50 kg K/ha 10 kg S/ha 0.5 kg Zn/ha	40 kg N/ha 2.0 kg Zn/ha
Crop sequence	Chickpea 2013 Wheat 2014 Sorghum 15-16 Chickpea 2016	Sorghum 13-14 Wheat 2015 Chickpea 2016*	Barley 2014 Mungbean 14-15 Sorghum 15-16	Wheat 2016

* crop failed due to disease pressure associated with wet season

Key site chemical fertility indicators are listed in Table 2, with chemical methods described in Rayment and Lyons (2011). Apart from Jimbour West, Colwell P values of the 0-0.1m are below the 95% critical soil test range for sorghum (17-30 mg P/kg), field pea (21-28 mg P/kg) and wheat (18-30 mg P/kg) (Bell et al. 2013) and all 0.1- 0.3m results under the tentative subsoil critical value of 10 mg P/kg (Guppy et al. 2012).

Table 2. Selected chemical characteristics for P experimental sites.

Depth **m**	**pH CaCl2**	**Colwell P** **mg/kg**	**BSES P** **mg/kg**	**Ca** **cmol/kg**	**Mg** **cmol/kg**	**Na** **cmol/kg**	**K** **cmol/kg**	**ECEC** **cmol/kg**
				Lundavra				
0.0-0.1	7.6	18	66	23.4	3.6	0.50	1.30	28.8
0.1-0.3	7.8	6	22	22.5	5.5	1.36	0.38	29.8
0.3-0.6	7.8	7	17	19.0	7.2	2.87	0.28	29.4
				Wondalli				
0.0-0.1	8.0	11	96	20.4	4.9	1.26	1.30	27.9
0.1-0.3	8.0	< 2	13	18.9	7.2	2.58	1.09	29.8
0.3-0.6	8.3	< 2	13	15.0	9.0	4.72	0.97	29.7
				Jimbour West				
0.0-0.1	7.2	37	98	16.1	9.4	1.26	0.40	27.2
0.1-0.3	7.5	8	12	13.6	12.3	2.86	0.18	28.9
0.3-0.6	8.1	4	7	12.9	15.5	5.13	0.22	33.8
				Mt Bindango				
0.0-0.1	6.9	19	48	21.9	7.2	0.67	1.14	30.9
0.1-0.3	7.2	3	16	27.1	7.9	1.34	0.49	36.8
0.3-0.6	6.9	<2	18	31.1	8.3	2.24	0.47	42.1

The exchangeable K values in the 0-0.1m layer were generally above the critical soil test range predicted for northern Vertosols (~0.4 - 0.6 cmol(+)/kg), (Guppy pers. comm.), and while the values in the 0.1 - 0.3m layer were often much lower, critical ranges for exchangeable K for this layer have yet to be defined.

Results and Discussion

Yields of ten site-years from the four sites are displayed in Table 3, with yields from one to four growing seasons reported for each experiment. The crops varied with site and rotation sequence, and consisted of 3 sorghum, 3 wheat, 2 chickpea, 1 barley and 1 mungbean crop. Responses have differed between sites and years and between crops at a site, but because crops and years/seasonal conditions are confounded, it is difficult to discern patterns of treatment responses for different species. However some patterns appear consistent at most locations.

Table 3. Grain yield (kg/ha) of untreated control (FR) and change in grain yield (kg/ha) with deep-placed P rate compared to FR.

Year	FR	0P	10P	20P	30P (40P Lundavra)	60P (80P Lundavra)	LSD ($P<0.05$)
				Lundavra			
13 Chickpea	1556	27	6	52	24	79	NS
14 Wheat	1960	80	84	138	182	247	140
15-16 Sorghum	3796	-288	-157	127	325	464	190
16 Chickpea	2537	34	18	-124	-45	-2	NS
Sum (n=4)		-147	-49	193	486	788	
				Wondalli			
13-14 Sorghum	2875	43	73	478	513	763	234
15 Wheat	3283	-171	215	621	881	918	418
Sum (n=2)		-128	288	1099	1394	1681	
				Jimbour West			
14 Barley	4180	273	488	704	741	1002	238
14-15 Mungbean	493	84	88	95	56	65	20
15-16 Sorghum	2428	192	242	312	385	386	228
Sum (n=3)		549	818	1111	1182	1453	
				Mt Bindango			
16 Wheat	4086	125	587	573	635	798	177

NS = not significant at 5% level

Increasing deep-placed P rate typically increased grain yields of cereal crops (wheat, barley, sorghum), although the rate of increase changes between sites. For example, contrast the response by wheat at Lundavra (a 247 kg/ha yield increase with 80 kg P/ha at triple superphosphate) with that of wheat or barley at three other sites, where applications of 30 kg P/ha (as MAP) increased yields by 600-900 kg/ha.

A lesser increase in aboveground biomass P uptake in response to P application at the Lundavra site (Table 4) was consistent with the small grain yield responses. Biomass P uptake increased by ≈ 2 kg P/ha at Lundavra, where the P source was triple superphosphate, compared to ≈ 5 kg P/ha at other locations where MAP was used (Table 4).

Conclusions

Low levels of plant available P in the subsoil (> 0.1m) are restricting cereal crop yields at all sites in most seasonal conditions. The residual benefits of deep bands suggest P fertility can be managed holistically across a crop rotation, improving yields but minimising the frequency of tillage operations in otherwise no-till cropping systems. Further research to explore interactions between deep placed P and other nutrient requirements would be beneficial, as will exploration of the longevity of response, and interaction between different rate/row spacing combinations and the root morphologies of different crop species.

Table 4. Above ground dry matter P uptake at maturity (kg P/ha) from untreated control (FR) and selected deep-placed P rates.

Year	FR	0P	20P	60P (80P Lundavra)	LSD (P<0.05)
			Lundavra		
13 Chickpea	5.1 a	5.0 a	6.2 ab	7.3 b	1.4
14 Wheat	5.8 a	5.3 a	6.8 b	7.3 b	1.0
15-16 Sorghum	12.5	10.9	12.9	13.2	NS
16 Chickpea	13.7	13.3	14.7	14.7	NS
			Wondalli		
13-14 Sorghum	6.9 a	8.0 a	10.2 b	11.3 b	1.9
15 Wheat	8.4 a	9.4 ab	11.9 c	11.0 bc	1.7
			Jimbour West		
14 Barley	11.5 a	12.5 a	14.5 b	16.6 c	1.5
15-16 Sorghum	9.8 ab	9.7 a	10.5 b	11.4 c	0.8
			Mt Bindango		
16 Wheat	14.1 a	15.4 ab	16.8 bc	17.1 c	1.7

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