Response to deep placed P, K and S in central Queensland

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Abstract
Two field experiments were established in central Queensland at Capella and Gindie to investigate the immediate and then residual benefit of deep placed (20 cm) nutrients in this opportunity cropping system. The field sites had factorial combinations of P (40 kg P/ha), K (200 kg K/ha) and S (40 kg S/ha) and all plots received 100 kg N/ha. No further K or S fertilizers were added during the experiment but some crops had starter P. The Capella site was sown to chickpea in 2012, wheat in 2013 and then chickpea in 2014. The Gindie site was sown to sorghum in 2011/12, chickpea in 2013 and sorghum in early 2015. There were responses to P alone in the first two crops at each site and there were K responses in half the six site years. In year 1 (a good year) both sites showed a 20% grain yield response to only to deep P. In year 2 (much drier) the effects of deep P were still evident at both sites and the effects of K were clearly evident at Gindie. There was a suggestion of an additive P+K effect at Capella and a 50% increase for P+K at Gindie. Year 3 was dry and chickpeas at Capella showed a larger response to P+K but the sorghum at Gindie only responded to deep K. These results indicate that responses to deep placed P and K are durable over an opportunity cropping system, and meeting both requirements is important to achieve yield responses.

Key words
Nutrient use efficiency, cropping systems, removal-to-use, fixed nitrogen, rotations.

Introduction
The northern Australian cropping region covers around 4M ha and is characterized by summer rainfalls on relatively heavy soils, which support summer crops (sorghum, mung bean) and winter crops (wheat, barley. chickpea) growing on incident or stored soil water respectively. Native 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). The reliance on stored subsoil water by winter crops means that roots growing in the moist subsoil exploit largely immobile K and P from that layer, while the drier topsoil reserves are not used. Unless deep soil samples are taken, these deficiencies can go unnoticed.

Over the long term that has been little P or K used, with the consequence that the exports of P and K are significant and primarily related to the grain yield of the crop. The removal of crop nutrients depends on the grain concentration and yield, with average rates P removal are around 2.9-3.2 kg P/t of grain for wheat, sorghum and chickpea, but K removal in chickpea (11.0 kg K/t) was at least twice that for wheat (4.1 kg K/t) and sorghum (3.1 kg K/t (Bell and Moody 2001). On average, cropped soils across all these northern regions contained 55% (±5%) of the exchangeable K reserves of the uncropped reference sites. This depletion is resulting in increasingly complex nutrient management decisions for growers (Bell et al. 2010, 2012). These results clearly confirm the impacts of multiple nutrient depletion and therefore declining soil fertility and so current research is evaluating strategies such as deep placement of K to address nutrient stratification.

The wetting and drying pattern of the soil, which in turn drives root growth and nutrient removal in the northern region means that the subsoils have become largely depleted of nutrients. The drier topsoils may show adequate soil test values, so that extractable K in the subsoil (10-30 cm) needs to be measured to determine K availability for crop growth (Bell et al. 2009, Moody et al. 2010). Revised soil testing protocols to take account of stratified nutrients have been proposed in some regions (Brennan and Mason 2006).

In response to these challenges, the hypothesis was developed that relatively high rates of nutrients could be place in the subsoil (10-30 cm) to provide for several crop phases. The initial application would see some disturbance, and the duration of the responses is uncertain. The experiments reported here aim to assess the long-term responses to P, K and S, alone and in combination, when placed at 20 cm.

Methods

Sites were selected in farmer's paddocks at Gindie (approx. 22 km south of Emerald) and Capella (approx. 50 km north of Emerald). Both sites had low P, K and S, especially in the subsoil layers (Table 1). The experiments were established by deep banding (~20 cm deep) using P (40 kg P/ha), K (200 kg K/ha) and S (30 kg S/ha) alone and in combination, and comparing performance to a deep ripped with no nutrients (control). Deep banding occurred during the 2011winter fallow and the bands were 50 cm apart. The sites were managed by the farmer as they would for the rest of the field, with crop selection and agronomic management following normal commercial practice for that soil type and region.

Biomass samples were taken to estimate crop growth and nutrient acquisition. Yield and grain nutrient concentration were also take by hand sampling to determine economic performance and nutrient removal. Crop sequences to date have been chickpea-wheat-chickpea-sorghum and sorghum-chickpea-sorghum at Capella and Gindie, respectively. No additional deep nutrients were provided after the initial treatments were applied, although some in-furrow fertilizers were applied at crop seeding, and this was across all experimental treatments.

Table 1 Soil test values at the start of the experiments at Gindie and Capella central Queensland.

		Gindie		Capella	
Analyte	unit	0-10 cm	10-30 cm	0-10 cm	10-30 cm
pH Ca		7.2	7.8	8.1	8.3
CEC	cmol(+)/kg	35.3	38.4	73.7	74.6
OC	%	0.6	0.5	0.7	0.7
Colwell P	mg/kg	13	<5	10	<5
BSES-P	mg/kg	10	5	14	9
Ex-K	cmol(+)/kg	0.17	0.07	0.46	0.16
KCl-40 S	mg/kg	3	2	3	2
DTPA Zn	mg/kg	0.2	0.1	0.3	0.1

Crop biomass and grain yields were measured, along with nutrient concentrations in the biomass, so that nutrient uptake values could be estimated.

Results and discussion

The soil test values for the two sites (Table 1) indicate low to very low Colwell P values, below the 95% critical soil test range for sorghum (17-30 mg/kg), field pea (21-28 mg/kg) and wheat (18-30 mg/kg) (Bell et al. 2013a, Bell et al. 2013b), while the ex-K values are around the critical soil test range for northern Vertosols (~0.4-0.6 cmol(+)/kg), (Guppy pers. comm.) at Gindie and Capella. The sulfur soil test values are near the critical range (2.4-3.2 mg/kg, Anderson et al. 2013) are also low, and so these sites reflect those with multiple subsoil deficiencies (Bell et al. 2010).

The grain yields over the six site years are summarized in Table 2. At Capella, there was little response to S alone but P alone showed a strong response in the first and second year crops, but not in the third crop. The response to K alone was significant only on the 2013 wheat crop, however when P and K were supplied together (as PK or PKS) the numerically highest yields were seen. Similar patterns were seen at Gindie in the first two crops, with combined P and K giving the highest yields, but in the 2014/15 sorghum K rather than P dominated this response.

Results have differed between sites, and among crops at a site. In the initial crop year, with good moisture availability, both sites showed a 20% grain yield response to deep P. While no other nutrients affected grain yields there was a suggestion of an additive effect of deep K at Capella in chickpea biomass, but this did not translate into a yield difference. Despite low soil S, neither site responded to applied S at either site.

In the much drier 2013 season (no in-crop rainfall after planting), effects of deep P were still evident at both sites (14% in Gindie chickpeas and 8% in Capella wheat), but effects of K were clearly evident only at Gindie. There was a suggestion of an additive P + K effect at Capella and a very significant additive effect of P + K at Gindie. The Gindie site was particularly interesting, as while the only nutrient limit at that site in the previous sorghum crop was P, the 2013 data suggest K availability was a greater limitation in the current chickpea crop (14% response to P but 27% response to K), while the additive effects of residual P and K were substantial (51% grain yield increase).

The reasons for the greater K response in 2013 could be related to seasonal conditions (no effective in-crop rainfall to allow access to shallow K reserves), crop species differences in K requirements (currently not known) or even agronomic factors such as crop row spacing (which influence available soil volume for root exploration). Regardless, of the nature of the interactions, these data illustrate that as soils reserves decline, it is essential to apply the right combination of fertiliser nutrients to maximise crop productivity and seasonal water use efficiency.

Year 3 was also a dry year, and chickpeas at Capella showed a response to P and K together, rather than when they were supplied alone. At Gindee, the sorghum crop did not response to added P, although the K responses were still sustained. The responsiveness of sorghum, which is grown on wide rows, is less clear as with a wet soil profile, the wider rows allow plants access to larger soils volumes, so that if the K supply is limited, the crop can extract adequate K even though it is at a lower soil concentration. The declining P response in year 3 at both sites suggests that the residual P may be approaching exhaustion after three crops, but the K rates applied (200 kg k/ha) are still available although the uptakes seen (Figure 1) are approaching the amount applied.

Table 2 Grain yields (t/ha) for crops grown with the various deep placed nutrition 2011 to 2015.

Site and crop/year	Control	K	P	S	PK	PS	KS	PKS	LSD (P<0.05)
				'Stranraer' Capella					
Chickpea 2012	2.33	2.34	2.75	2.32	2.89	2.79	2.30	2.83	0.17
Wheat 2013	2.08	2.19	2.25	2.19	2.36	2.25	2.20	2.34	0.09
Chickpea 2014	1.51	1.59	1.57	1.53	1.69	1.65	1.60	1.75	0.10
				'Bendee' Gindie					
Sorghum 2011/12	2.32	2.39	2.78	2.36	2.90	2.81	2.35	2.81	0.14
Chickpea 2013	1.15	1.47	1.32	1.21	1.74	1.18	1.52	1.61	0.26
Sorghum 2014/15	2.94	3.40	2.99	2.90	3.38	3.25	3.19	3.25	0.20

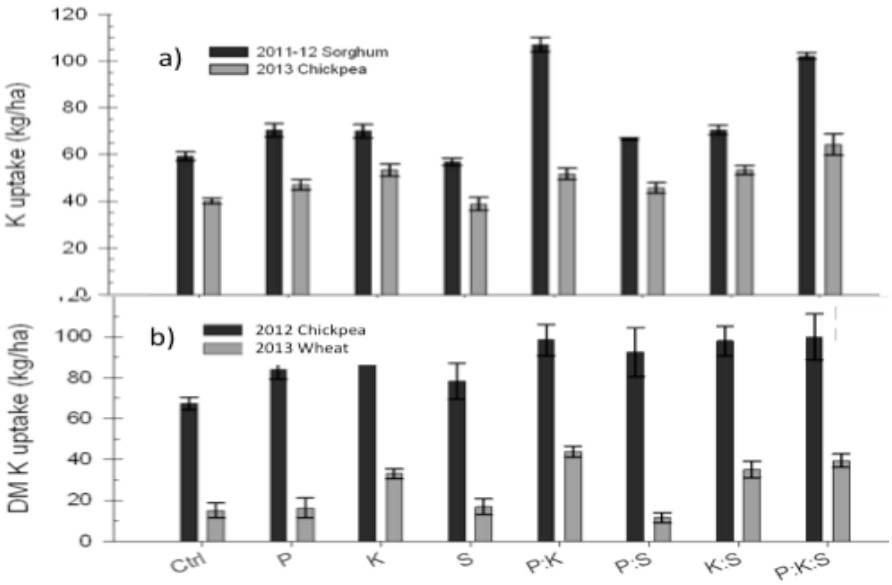

Figure 1. Uptake of K in total dry matter in response to deep placed nutrients at a) Gindie in 2011 and 2013, and b) Capella in 2012 and 2013.

Conclusion

Nutrients deep placed (20 cm), in this case P and K, showed responses over a range of crops and environmental conditions. Responses were more apparent in drier years where crop roots drew water and nutrients from the subsoils rather than from a larger soil volume. These responses were seen for at least three crops over four years, indicating the feasibility of deep placement at the start of a cropping cycle to meet nutrient demands in this opportunity cropping system.

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