Sub-soil constraints affect responsiveness of wheat to applied Phosphorus

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Abstract
Physiochemical factors in the subsoil, such as high boron (B) and salinity, are major constraints to crop growth and grain yield in Australian grain production systems. Many farmers have noted large vegetative responses to phosphorus (P) fertilisers which subsequently fail to translate to a grain yield response. This experiment tested the hypothesis that the lack of grain yield response by wheat (cv. Yipti) to fertiliser P was due to the effect of sub-soil constraints (SSCs). A glasshouse experiment, using a grey Vertosol in 55cm long PVC cores, was established with a factorial design of plus/minus SSCs (salt & boron) and 0 or 24kg P/ha P fertiliser banded at 5cm. Cores were harvested at 3 growth stages (GS25, GS65 & GS92), with a plus or minus water stress imposed after anthesis ("drought" treatment). Early biomass was affected by P fertiliser and the presence of SSCs individually, but there was no significant interaction. By anthesis, however the response to P application was significantly ($P<0.001$) affected by SSC's and this effect continued to maturity. At maturity the biomass and grain yield response to applied P fertiliser was significantly ($P<0.001$) greater in the presence of SSC's compared to without SSC's. The relative response of grain yield to P fertiliser in the absence of SSC's was 84%, compared with 48% when present. Post anthesis water stress did not affect grain yield nor the response to P fertiliser. These findings suggest that good P nutrition has an important role for crop production in the presence of SSCs and refute the hypothesis.

Key Words
Sub-soil constraints, phosphorus, post-anthesis water stress

Introduction

A range of Australian field studies (Armstrong *et al.* 2008; Mason *et al.* 2010), using both fluid and granular P, have noted the failure of significant dry matter responses to applied P during early vegetative stages to translate to grain yield responses at maturity. This observation has reinforced the perception that current commercial soil tests e.g. Colwell, are poor at predicting grain yield responses to applied P.

There are several proposed explanations for this lack of response. One is likened to the "haying off" effect observed with a luxury supply of nitrogen is provided to grain crops during early growth followed by a 'dry finish' (van Herwaarden *et al.* 1998), which has been attributed to a combination of lack of soil water resulting in reduced post anthesis assimilation, a failure to fully extract soil water (attributed in part to the presence of subsoil constraints) and an apparent inadequate retranslocation of pre-anthesis reserves to compensate for the lack of pre-anthesis assimilation.

Knowing the cause behind this lack of grain yield response to applied P and the relationship with seasonal soil moisture conditions and subsoil constraints is important for P fertiliser management. This experiment aims to determine whether sub-soil constraints, through the impact on root growth and therefore access to water and nutrients, could explain the failed grain yield response to applied P fertiliser in wheat.

Methods

Experimental design

A glasshouse experiment was established with a factorial design of plus/minus SSCs (NaCl & Boron), 0 or 24 kg P/ha (added as $NaH_2PO_4.2H_2O$ solution) and plus/minus imposition of post-anthesis water stress. Boron and salt levels were determined during a pre-trial response curve. Boron was applied at a rate of 60mg B/kg soil and salt was added as NaCl at a rate of 4.95 g NaCl/kg soil. Solutions were applied to a sub-sample of soil using a battery powered spray applicator. Soil was then oven dried at <40°C before being mixed with the bulk soil. Two extra rates of P (12k gP/ha & 36 kg P/ha) were incorporated into the design, plus and minus SSC, to produce a response curve. These treatments were harvested at grain maturity and did not experience water stress. All treatments were replicated 3 times as a randomised complete block design. The top-soil (0-10 cm) contained no added NaCl and Boron, but had basal nutrients (N, Cu, Zn & K) applied to ensure only P was limiting. An extra 75 kg N/ha was applied between mid till and anthesis, and a foliar application of Zn was applied to help correct visual signs of deficiency. Where P was applied it was banded just below the seed, at a depth of 5cm. Each core (55 cm long & 15 cm diameter) was sown with 6 wheat (c.v. Yitpi) seeds, before thinning to 4 plants at 2 leaf stage. Polyethylene beads were added to minimise evaporation. Cores were kept at 90% of field capacity until anthesis when the water stress treatment was imposed. Watering of ‘drought’ treatments ceased at anthesis whereas non-drought treatments were maintained at field capacity by watering twice weekly until just prior to physiological maturity.

Soil

The soil used was a grey Vertosol soil (Isbell 1996) that was very low in plant available P as determined by both the Colwell (Colwell 1963) and DGT methods (Mason *et al.* 2010). The soil was air dried and ground (< 5 mm). Basic physio-chemical properties of the soil are presented in Table 1.

Table 1. Soil characteristics of grey Vertosol

Soil	pH ($CaCl_2$)	$EC_{(1:5)}$ (dS/m)	Hot CaCl2 Extractable B (mg/kg)	Total N (%)	Total C (%)	Total P (mg/kg)	DGT-P (µg/L)	Colwell P (mg/kg)	Colwell K (mg/kg)	PBI
Minus SSC	7.45	0.46	2.6	0.14	3.02	87	3	8	514	133
Plus SSC	7.55	2.68	69							

Data collection

Crop water use was determined by recording the weight of each cores before each watering. Cores were harvested at mid tillering (GS25), anthesis (GS65) and grain maturity (GS92). Shoot material was dried at 70°C and weighed, before being ground (< 0.5 mm). Total P determined by ICP following acid digest. At grain maturity, grain yield and Leco N were measured. The soil profile was separated into 4 depths (0-10, 10-20, 20-30 and 30-50 cm) and washed out over a 1mm sieve. Roots were collected and dried at 70°C before being weighed. Soil moistures were obtained by taking sub-samples during excavation of the final harvest and drying them at 105°C. $EC_{(1:5)}$ was also measured.

Statistical analysis

Data was analysed in GenStat V13.1 using ANOVA and REML. Transformations were applied where appropriate.

Results

There were early shoot growth responses to both P fertilisation and SSC’s (P<0.001) from GS25. By anthesis, a significant interaction (P=0.001) was noted with the response to applied P relatively greater where SSC’s were present (Table 2).

Table 2. Summary of the impact of SSC’s, P fertilisation and post anthesis water stress on the dry matter production, yield components and nutrient analysis. DM = dry matter, GY= grain yield, HI= harvest index. Effect of soil moisture was not significant.

Soil	*P Fert (kgP/ha)*	*Water treatment*	*Mid Till*		*Anthesis*		*Maturity*					
			DM (g/core)	*Shoot P uptake (mg/core)*	*DM (g/core)*	*Shoot P uptake (mg/core)*	*DM (g/core)*	*GY (g/core)*	*HI*	*Grain protein (%)*	*Grain P content (mg/core)*	*Straw P content (mg/core)*
Plus SSC	0	Non-limiting	1.4	2.3	7.4	9.3	14.1	6.0	0.42	15.9	13.1	1.4
		Drought	-	-	-	-	12.9	4.9	0.37	14.6	8.9	1.1
	24	Non-limiting	3.3	11.1	17.9	33.3	31.1	12.6	0.41	12.7	38.9	3.2
		Drought	-	-	-	-	29.2	12.8	0.44	12.2	37.4	3.1
Minus SSC	0	Non-limiting	3.0	8.0	20.0	32.4	33.2	11.8	0.36	12.0	28.4	3.4
		Drought	-	-	-	-	30.5	10.8	0.35	12.1	31.2	3.1
	24	Non-limiting	5.2	18.1	23.9	50.7	36.8	14.0	0.38	10.3	42.3	6.5
		Drought	-	-	-	-	35.1	14.4	0.39	9.9	49.3	5.4
Fpr.			SSC*** Pfert***	SSC*** P fert***	P fert x SSC**	SSC *** Pfert***	P fert x SSC***	Pfert x SSC***	n.s	SSC*** Pfert***	SSC x Pfert**	SSC*** P fert*** Moisture*
l.s.d (*P*=0.05)			0.633	2.214	1.933	2.958	2.676	1.144	n.s	0.680	3.818	0.451

This interactive effect, on dry matter, continued to grain maturity (P < 001) and ultimately affected grain yield (P<0.001). Post anthesis water stress did not significantly affect either dry matter (P=0.216) or grain yield (P=0.860). On a relative basis, there was a reduction in response to P for the minus SSC between mid till biomass (58%) and grain yield (84%). This reduction was not observed where SSC’s were present (42% at mid till & 48% for grain yield).

Harvest index was not significant, suggesting there were no haying off effects. Response curve data indicates, without SSC's, 12 kg P/ha was sufficient to obtain maximum yield. However, where SSC's were present the maximum yield was obtained when more than 24kg P/ha was applied (data not presented).
Tissue P content at mid till and anthesis showed a significant increase with P fertilisation (P < 0.001) and a decrease where SSC's were present (P < 0.001), but no interaction (Table 2). Grain P content was increased by P fertiliser and the absence of SSC's (P=0.003) (Table 2). Grain protein significantly decreased with P fertiliser (P<0.001) and increased with SSC's (P<0.001), suggesting N application was insufficient. Soil moisture did not significantly affect grain protein (P=0.149) or P content (P=0.605).
Where no SSC's were present, wheat roots grew below 30cm by GS25 (data not presented) and continued to accumulated at depth over time. At grain maturity, there was a significant interaction (P = 0.028) between depth, P fertiliser, SSC's and soil moisture (Figure 1).

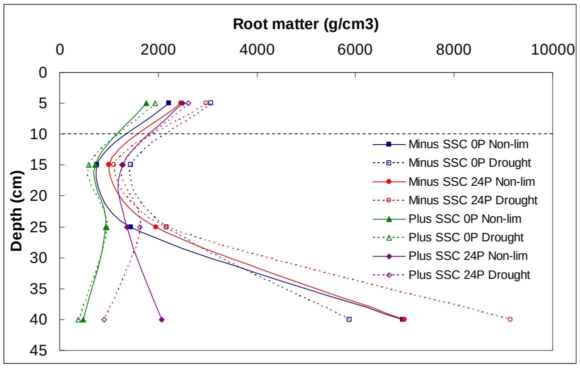

Figure 1. Root growth at maturity (g/core) Black dotted line at 10cm indicates where the presence SSC's commenced, from 10cm downward. Significant 4 way interaction between Depth, P fertiliser, SSC's and soil moisture (P=0.028)

When SSC's were present, the wheat used significantly less water, especially when no P was applied (P<0.001) (Figure 2), corresponding to reduced root growth (Figure 1). When P was applied, both shoot and root growth was simulated and water use increased. Without SSC's there was little difference water use between P treatments. Drought significantly (P = 0.004) decreased total water use (Figure 2). Soil moisture at grain maturity was significantly affected by SSC's, drought treatment and depth (P=0.001) (data not presented). Where SSC's were present more water remained at grain maturity, especially deep in the profile.

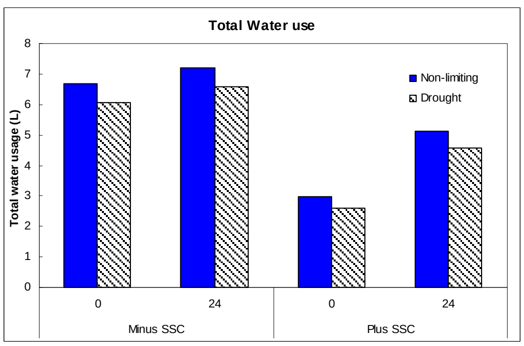

Figure 2. Total crop water use at final harvest. P fert x SSC interaction l.s.d = 0.574. Soil moisture lsd = 0.406

Discussion

Our experiment found that responses to P during early vegetative stage subsequently translated to a grain yield response, in contrast to anecdotal field observations. The change in relative response between mid till and grain yield, where SSC's were absent further refutes the hypothesis and suggests another factor such as Nitrogen may be responsible. As hypothesised the presence of SSC's did reduce root growth into the sub-soil and thus affected water use and nutrient uptake. Without SSC's root growth at depth was unimpeded and was only restricted by the core length. It is assumed that under field conditions in soils, in the absence of any subsoil constraint, roots would have continued to grow further into the sub-soil. In contrast, where subsoil constraints are present, root growth can be severely affected (Nuttall *et al.* 2003).
While the drought treatment affected soil moisture content and total water usage, the initial soil moisture in the core was sufficient for the wheat to reach maturity without any significant impact on grain development, as shown by the soil water remaining at maturity regardless of whether SSCs were present. In the field soil

water in the topsoil would often be depleted by anthesis and hence plant available P (derived from both fertiliser and soil), and which tends to be highly vertical stratified in the topsoil (Singh *et al.* 2005), would be effectively unavailable for crop use (Pinkerton and Simpson 1986). This phenomenon suggests that P uptake early in the season, when moisture in the topsoil tended to be consistently greater, would be critical for subsequent crop P nutrition.

Since grain number is predominately determined prior to anthesis (Kirby 1988), water stress imposed after anthesis would have had little affect on grain number, but would affect grain size. If the "drought" treatment had been imposed earlier, so that the wheat had experienced water stress at anthesis, the impact on yield may have been more severe.

A series of dry years, during the early 2000's, coincided with the conduction of field trials that observed this phenomenon. During this period soil water in the topsoil during early vegetative stages was often adequate, but the absence of large rainfall events meant there was little or no subsoil water. As a result the crop still experienced 'haying off' as indicated by small harvest indexes (Armstrong pers comm.). Furthermore, subsoil constraints had little impact on crop grain yield responses (Nuttall and Armstrong 2010). The lack of grain yield response to P previously observed may represent the crop needing to send its roots deep into the profile during latter development stages to access soil water but the lack of a ready P supply in the subsoil (due to vertical stratification) may have resulted in a premature cessation of nutrient uptake needed to complete grain development.

Conclusion

This experiment found little evidence to support the hypothesis that the presence of soil physicochemical constraints in the subsoil, such as high B and salinity, were responsible for the failure of crops such as wheat to translate early vegetative response to applied P to grain yield responses. Instead we found that dry matter responses to applied P in the early growth did translate into a yield response at maturity. However, the timing and severity of the post-anthesis water stress, along with a potential N limitation may have affected our results which may explain the discrepancy with field observations.

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