Pulse Phosphorus requirements and impacts on Nitrogen fixation

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Abstract

High commodity prices for several pulse (grain legume) crops over the last five years have meant that crops such as lentil and chickpea have become highly profitable and sowing frequency within rotations has increased significantly in cropping regions of South Australia. Limited information on the nutritional requirements of these pulses has meant that nutrient requirements cannot be calculated based on soil test levels. Recent trials by Wilhelm et al. (pers comm.) have focused on Phosphorus (P) requirements of selected pulses and attempted to determine soil P test critical levels compared to those established for cereals but these trials were not N limited (i.e. N fertiliser applied) and N fixation was thus not considered.

Two P response trials in the Mid-North and central Yorke Peninsula of South Australia investigated the response of lentils and chickpeas to P applications and measured the amount of N fixed with increasing P application. In-season assessments showed higher P requirements for both pulse crops (particularly lentils) compared to wheat. The increase in pulse biomass with increasing P rates coincided with increases in both nodule number but also nodule weight per gram of root. The benefits from optimising pulse production occurred at P rates higher than what is considered district practice for these crops. Dry seasonal conditions meant that the early season increases in biomass didn't translate to grain in 2018. However, nitrogen fixation estimates (by ^{15}N natural abundance) were highly related to early season nodulation, particularly for lentils.

Key Words

Phosphorus, Nitrogen fixation, Lentils, Chickpeas

Introduction

Pulse crops are a key component of cropping systems in southern Australia, however their nutritional requirements for optimal production have had less attention than their cereal counterparts. P is not only a primary nutrient essential for plant growth and development it is also required for energy transformation in legume nodules (Udvardi and Poole 2013) and is positively associated with improved N_2 fixation (Rotaru and Sinclair 2009).

Recent trials performed in South Australia assessing responsiveness of wheat to P found that gross margins can be significantly lifted by increasing P rates on soil types that have a moderate to high ability to fix P. Many of these soil types are in regions (e.g. Yorke Peninsula, Mid-North) where pulse crops (e.g. Lentils, Chickpeas) can be an important component of crop rotations. Growers tend to decrease their P rates inadvertently when growing a pulse as requirements for starter N inputs (not required due to N fixation) are reduced (through lower MAP, DAP application rates). Therefore, there is a significant risk that the P requirements of pulse crops are not currently being met, lowering gross margins and N_2 fixation potential. Poor P nutrition will severely hinder early biomass growth and if severe enough grain yields. By increasing biomass and yields through improved P nutrition there is the potential to increase pulse N_2 fixation and soil N reserves for the following cereal in rotation. Two replicated P response trials using lentils and chickpeas next to wheat (used as a benchmark) were performed in 2018 to assess response dynamics of the three crops and to assess the impact of increasing P applications on the ability of pulse crops to fix N.

Methods

Two replicated P response trials (randomised split block design) which included two pulse crops (lentils and chickpeas) and wheat were sown at two locations in South Australia, Brinkworth in the mid-North and Urania on central Yorke Peninsula (YP). Starting soil P levels were low and responses to applied P were expected based on P requirement data for wheat (Table 1). Specific trial details can be found in Table 2.

Early biomass assessment was performed using a greenseeker when wheat was at the end of tillering (GS30). Nodule number and weight per plant and root and shoot weight per plant was assessed by sampling 8 plants per plot at approximately 12 weeks after sowing for three P treatments (0, 10 and 50 kg P/ha) at both sites.

10 plants per plot were taken near peak biomass (Full pod at Brinkworth and mid pod fill at Urania) along with Canola reference plants, dry weights per plant were measured and N_2 Fixation using the ^{15}N natural abundance technique (Unkovich et al. 1997).
Grain was removed using a plot harvester and grain yield and quality assessed.

Table 1. Starting soil P and N levels as measured by various soil tests at both trial sites.

Site	DGT P (ug/L)	Colwell P (mg/kg)	PBI	Nitrate N (mg/kg)	Critical Colwell P (mg/kg)	Total N (kg/ha)
Brinkworth	13	18	90	19	27	50 (0-60cm)
Urania	9	19	123	22	30	30

Critical values (wheat):
DGT = 48-60 ug/L
Colwell P = 27 mg/kg and 30 mg/kg for Brinkworth and Urania respectively.

Table 2. Specific details for the two P response trials comparing the performance of two pulse crops with wheat. Treatments were replicated 3 times.

Trial details	Trial 1 Brinkworth (mid-North)	Trial 2 Urania (YP)
Crop (Variety)	Wheat (Mace), Chickpea (Genesis 090), Lentil (Hurricane)	
Sowing date	25 May 2018	26 May 2018
Treatments	5 P rates (as Pasture King, no N), 0, 5, 10, 20, 50 kg P/ha N requirements for wheat met with Urea	
Harvest	5 December 2018	10 December 2018

Analysis

Nodulation and biomass data were analysed using ASreml- R, where site was a factor and corresponding block and treatment structure design was constrained to each site. Yield was analysed using GENSTAT 18th edition in a two-way split plot ANOVA.

Response curves were fitted to both biomass estimates and grain yields obtained at each P rate using a Mitscherlich equation in the form of:

$Y = y_0 + a*(1-\exp(-b*x))$

Where y_0 is the yield obtained with no applied P, a is the overall response to applied P, $y_0 + a$ is the yield maximum obtained at each site, b is the response curvature to applied P which is represented by x.

Optimal P requirements were calculated using the following equation and based on obtaining 90% of the overall grain yield response.

Where $x = y_0 + (0.9*a)$

Results

In-season measurements

NDVI biomass Measurements showed responses to applied P were clear at both sites and similar trends were found between the three different crop types. Chickpea and wheat had similar P response characteristics, but linear responses were found for Lentil indicating P rates greater than 50 kg P/ha (highest P rate applied) were required to maximise biomass at this growth stage (Table 2).

Table 3 Comparative early biomass responses of chickpea, lentil and wheat to applied P at both sites and the corresponding optimal P required to reach maximum yields. *Linear responses meant that higher rates of P addition would be needed to maximise plant growth. Relative yield = NDVI control/NDVI max*100.

Site	Crop	NDVI control (0P)	NDVI max	Relative yield (%)	Optimal P (kg/ha)
Brinkworth	Chickpeas	0.27	0.32	84	40
	Lentils	0.30	0.37*	81*	>50
	Wheat	0.33	0.44	75	26

Urania	Chickpeas	0.32	0.38	84	50
	Lentils	0.38	0.45*	86*	>50
	Wheat	0.54	0.70	77	47

Nodulation counts

There was a significant ($p < 0.05$) main effect of P rate across sites and crop species, whereby both nodule number per plant (data not shown) and nodule dry weight per gram of root (Figure 1) were increased with increasing P rate (0P vs 50P significant). Chickpea produced more nodules per gram of root than lentil at Brinkworth but not at Urania.

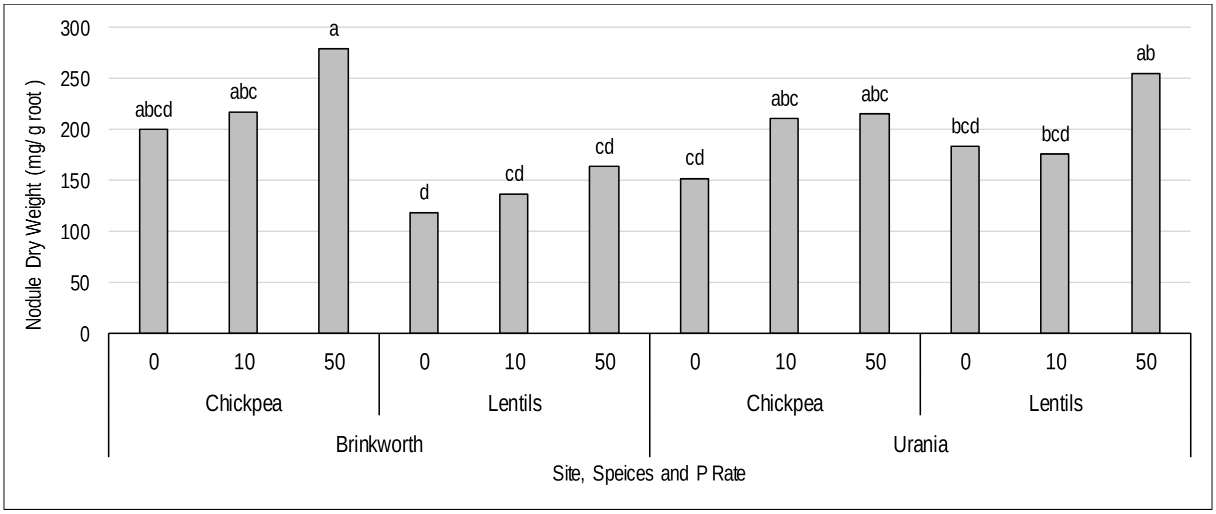

Figure 1 Effect of P nutrition (0P, 10P and 50P) on nodulation (dry weight per gram of root) of chickpea and lentils at Brinkworth and Urania in 2018. Different letters denote values are significantly different ($p < 0.05$).

Grain yields

Yield responses for both chickpeas and lentils at both sites were erratic mainly due to the poor finish to the season and significant wind events which flattened crops, reducing harvestability. Pulse yields at Brinkworth were very low and in combination with site variability responses to P were hard to interpret generating low correlation values (R^2) between P rates used and yields obtained (Table 4). Pulse yields at Urania were also poor compared to the yields obtained for wheat. The significant delay between desiccation and harvest due to rainfall events may have contributed to the low pulse yields. (Table 4).

Table 4 Comparative grain responses of chickpea, lentil and wheat to applied P at both sites and the corresponding optimal P required to reach maximum yields. NR denotes not responsive.

Site	Crop	Grain yield (t/ha) 0P	Grain yield (t/ha) Maximum	Relative yield (%)	Optimal P (kg/ha)
Brinkworth	Chickpeas	0.339	0.498	68	5
	Lentils	0.088	0.121	72	5
	Wheat	1.570	1.770	89	NR
Urania	Chickpeas	1.180	1.220	97	NR
	Lentils	0.809	0.927	87	5
	Wheat	4.264	5.147	83	16

Nitrogen fixation

There was a significant difference in the total amount of N_2 fixed (measured in shoots) between standard P rates (10 kg P/ha) and higher P rates for lentils at Urania, with approximately 40 kg/ha more fixed in the latter (Figure 2). Trends showed that N_2 Fixation generally increased with P rate for Urania but less so for Brinkworth where there were no significant treatment effects, likely related to the poor finish. There was a highly significant relationship between nodule number per plant early in the season (12 weeks) and the amount of N_2 fixed at peak biomass (Figure 2) driven by the differences in nodule number and amount of N fixed between the two sites, relationships between sites are weaker. The differences in nodulation and amounts of N fixed between sites highlights the importance of good nodulation to maximise pulse production and N_2 fixation, and P nutrition may play a key part in this (e.g. lentils at Urania).

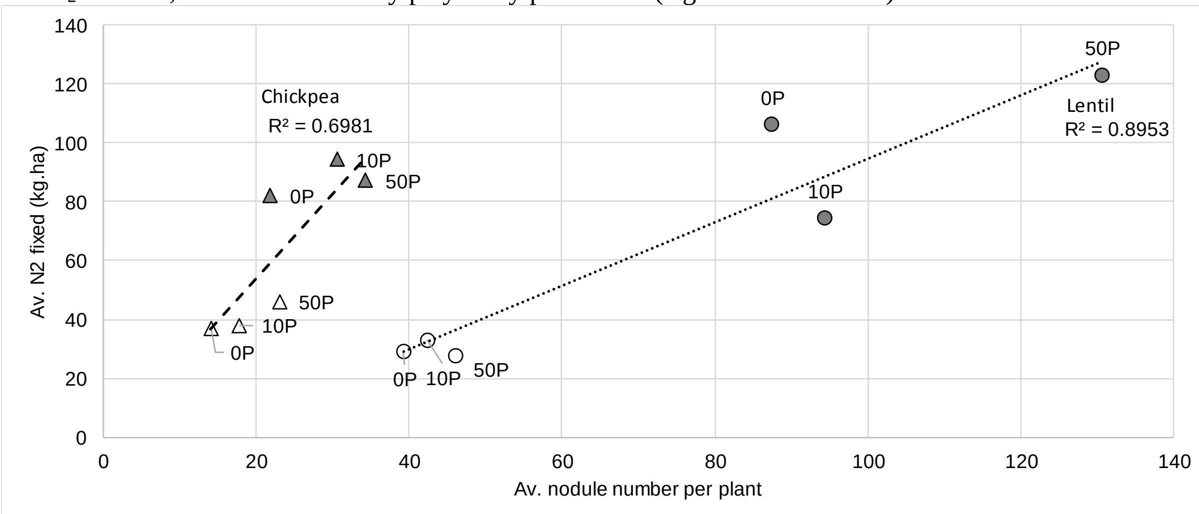

Figure 2 Relationship between nodule number per plant (measured at 12 weeks) and the nitrogen fixed (shoot – kg/ha estimated at peak biomass) for lentil (○) and Chickpea (△) grown at Brinkworth (open symbols) and Urania (filled symbols) at three P rates (0P, 10P, 50P).

Economics

Simple economic analysis for both pulse crops at both sites (2018) which include the cost of applied P treatments, income from corresponding grain yields, conversion of the amount of N_2 fixed into a urea equivalent revealed that low P rates (5-10P) produced the highest gross margins for both crops at Brinkworth (data not shown). This was mainly due to the poor returns from low grain yields. At Urania, 10P produced the highest gross margin for chickpea but 20P was the highest gross margin treatment for lentils. It is important to consider that this economic analysis uses an initial estimate of the amount of N_2 Fixation and no consideration of the economics resulting from the performance of the next crop in rotation.

Conclusion

Early biomass P requirements for two important pulse crops (lentils and chickpeas) grown in South Australian broad acre cropping regions are as high and if not greater than that for wheat. The extra biomass associated with increasing P application generated increases in overall nodulation numbers but also nodule weight per gram of root. The increase in nodule weight per gram of root suggests the increase in nodulation in partially independent of the increase in plant size due to improved P. Nitrogen Fixation measurements were highly correlated to nodule number by combining the two trial locations potentially highlighting the importance of maximising early pulse performance but more results are required to improve within site relationships. This work outlines the importance of P nutrition for pulse production on selected soil types, but further research is needed to determine optimal P levels at a production and economic level in a good season as well as determining the most efficient fertiliser type is to deliver adequate P inputs but not hinder pulse N fixation through extra N applied via DAP/MAP.

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