Effect of rate and placement of phosphorus on vetch performance

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Abstract
Phosphorus (P) is an essential nutrient which influences plant growth. Inadequate P restricts root and shoot growth and other functions that reduce N fixation by legumes. Vetch (*Vicia sativa*), a versatile pasture legume crop that can be used for grain, pasture, hay/silage or green manure, is being grown on naturally infertile Mallee soils which are often quite deficient in P. Consequently, it struggles to achieve optimum productivity and hence less fixed nitrogen is returned to the system. This project evaluated the impact of P on vetch productivity and nodulation and also investigated placement of P at sowing on nodulation, root and shoot dry matter (DM) production. Results showed that there are productivity gains to be realised from applying P fertilisers when sowing vetch on soils with low P reserves. Application of 32 units of P resulted in shoot DM increases of 239% and 45% at Loxton and Peebinga respectively. Results also showed that deep placement of P is beneficial to early and late DM production, but can set back nodulation as the plants need the P upfront. P applications, however, need to be matched against expected productivity gains for different soil types and rainfall regions to make sure that the fertiliser applications are economically justifiable

Key words
Phosphorus, vetch, nodules, root and shoot biomass, phosphorus agronomic efficiency

Introduction
Vetch is now a significant legume component of cereal cropping systems in Australia's low and medium rainfall zones. It's versatility as a valuable forage legume has allowed it to spread to areas where other pasture legumes fail to perform. In 2016, approximately 32,000 ha of vetch was grown in South Australia (SA), with 32% of that area being grown in the SA Mallee region (Rural Solutions, 2017). An important benefit derived from vetch production is the significant amounts of nitrogen (N) returned back into the soil. Results from the Australian National Vetch Breeding Program across five sites over three years have shown that total nitrogen in the soil increased by 56 kg/ha after a vetch grain crop. Matic and McColl (2012) reported nitrogen returns of 94 kg/ha after vetch hay production and 154 kg/ha of soil nitrogen after green manuring. Cereal yields following vetch have the potential to be at least 30-50% higher than in a continuous cereal sequence (Unkovich et al 1997; Rochester, 2004). Among other factors, low phosphorus in Mallee soils is possibly restricting vetch crops to perform below their full potential for dry matter and N production. P plays a key role in the symbiotic N fixation process by increasing shoot and root growth, decreasing the time needed for developing nodules to become active and benefit the host legume, increasing the number and size of nodules and the amount of N assimilated per unit weight of nodules, and increasing the percent and total amount of N in the harvested portion of the host legume (Armstrong, 1999). By addressing the issues of optimal rate of P and placement, productivity gains in the form of improved dry matter production, grain yield, nodulation and N-fixation can result in multiple benefits particularly in low rainfall mixed farming systems. In this investigation, we evaluated the effects of P fertilisation on dry matter production and nodulation of vetch in low rainfall mixed farming systems of South Australia.

Methods
Two replicated field trials were established in 2018 at sites representative of alkaline sandy soils in the northern Mallee of SA; a grey sand with clay underneath at Peebinga (pH water 8.23) and a red loamy sand at Loxton (pH water 7.41). Both trial sites had a low level of Colwell P in the top 10 cm (Peebinga 5 mg P/kg, Loxton 8 mg P/kg). Trials were sown to cv. Volga vetch @ 35 kg/ha on 13 June (Loxton) and 14 June (Peebinga). Different rates of P were applied as triple superphosphate (TSP), at different depths below the seed (Table 1). Plot length was 15 m and plot width was 2m and all treatments were replicated three times.

Table 1: P rates and placement treatment details

Main plot factor (P placement)	With seed, Shallow (4cm below seed), Deep (8cm below seed)
Sub-plot factor (kgP/ha)	0 (control), 4, 8, 16, 32

Both trials were designed as factorial Randomised Complete Block Designs with 3 replicates. All treatments received a trace element package of 1 kg/ha Zinc, 2kg/ha Manganese and 1 kg/ha Copper at sowing to make sure the responses to applied P were not restricted by trace element deficiencies. Emerged plants were counted on 10 July to determine plant population and Clethodim @ 250 ml/ha + 1 L/ha wetter was applied at both trial sites on 28 August to control grass weeds. Sampling for nodulation, leaf tissue P, and early shoot and root dry matter (DM) was done on 5 September. Late flowering/early podding DM cuts were done on 22 October to determine maximum biomass.

Results

With total growing season rainfall of 116 mm (Peebinga) and 106 mm (Loxton), plant productivity was low at both sites. Visual responses to the different rates of P applied at different depths were more evident at the Loxton site than at Peebinga.

Response to P: At both sites, there was a general increase in leaf tissue P with increasing soil P, and the same trend was observed in terms of shoot DM, root DM and nodulation numbers (Table 2). Average early shoot DM was higher at Loxton (382 kg DM/ha) than at Peebinga (317 kg DM/ha).

Table 2: Effect of different P rates on leaf tissue P, nodulation, early shoot and root DM at Loxton and Peebinga

Site	**P rate** (kg/ha)	**Leaf tissue P** (%)	**Nodulation** (# nodules/root)	**Early shoot DM** (kg/ha)	**Root DM** (mg/root)
LOXTON	0	0.27	6	168	95
	4	0.28	11.3	312	251
	8	0.27	11.3	342	431
	16	0.31	15	446	315
	32	0.33	27.8	641	456
	lsd (5%)	***0.03***	***4.8***	***123***	***190***
	p value	***<0.001***	***<0.001***	***<0.001***	***0.004***
PEEBINGA	0	0.23	8.4	241	96
	4	0.25	11.9	320	12
	8	0.27	12.6	278	138
	16	0.28	16.3	352	127
	32	0.36	19.9	396	139
	lsd (5%)	***0.03***	***6.4***	***102***	***23***
	p value	***<0.001***	***0.01***	***0.03***	***0.005***

Increasing rates of P also progressively increased flowering shoot DM at both sites (Figure 1). At both sites, the biggest response to applied P was from the nil treatment to 4 kgP/ha. The response was greater at Loxton (85%) and less at Peebinga (16%).

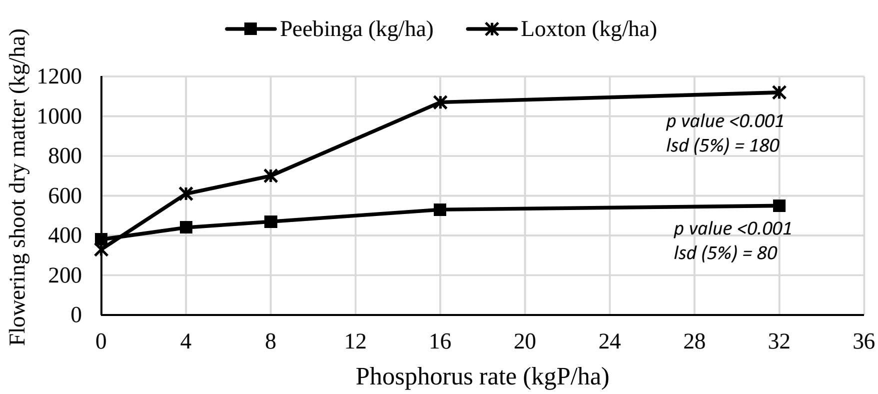

Figure 1: Effect of phosphorus of flowering shoot DM at Loxton and Peebinga

Responses to P placement: There was no response in leaf tissue P at the Loxton site, however early shoot DM increased with increasing depth of P placement. Deep banding P resulted in better early biomass production but resulted in the least amount of nodules per root. At the Peebinga site, there was no response in terms of leaf tissue P, nodulation or shoot DM when P was placed at different depths away from the seed (Table 3). Placing P with the seed at sowing rather than banding P improved root DM at Peebinga but not at Loxton.

Phosphorus agronomic efficiency (PAE) is calculated in units of yield increase per unit of nutrient applied. It more closely reflects the direct production impact of an applied fertilizer and relates directly to economic return (Fixen et al., 2014). Mean PAE was higher at Loxton (47 kgDM/kgP) than at Peebinga (10 kgDM/kgP), meaning that the impact of applied P was greater on shoot biomass at Loxton. Deep placement of P had the largest PAE response at Loxton (55 kgDM/kgP) while placing P with the seed at sowing had the lowest response (34 kgDM/kgP). At Peebinga, banding P gave the largest PAW response (24 kgDM/kgP) with deep banding giving the lowest response (1 kgDM/kgP).

Table 3: Effect of P placement on leaf tissue P, nodulation, early shoot and root DM at Loxton and Peebinga

Site	**Placement**	**Leaf tissue P** (%)	**Nodulation** (# nodules/root)	**Early shoot DM** (kg/ha)	**Root DM** (mg/root)
Loxton	Deep banded	0.29	10.9	461	240
	Banded	0.30	17.0	385	350
	With seed	0.29	14.9	298	339
	p value	***ns***	***0.008***	***0.006***	***ns***
Peebinga	Deep banded	0.28	13.6	352	115
	Banded	0.28	12.6	309	119
	With seed	0.28	15.2	292	139
	p value	***ns***	***ns***	***ns***	***0.02***

Fitted exponential curves (Figure 2) were used to derive estimates of the rate of change of PAE with changes in P applied. At both sites, there was a similar trend of decreasing PAE with increasing rate of P applied. The rate of PAE decrease was higher at Peebinga, decreasing by 2.68 kg DM per kilogram of P added compared with 0.97 at Loxton.

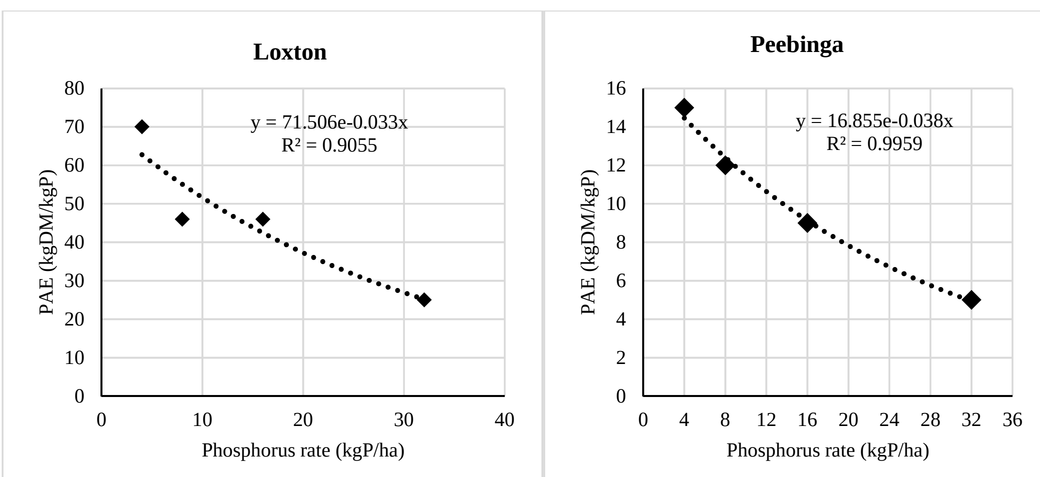

Figure 2: Phosphorus agronomic efficiency (kgDM/kgP) at Loxton and Peebinga

The calculation of the gross margin (GM) analysis (Table 4) only considered gross income from vetch hay (flowering DM) and the main variable cost i.e. cost of TSP/ha. The assumption was TSP at a cost of $600 /ton and vetch hay at $440 /ton (Agtrader.com, 2019). The GM analysis consistently shows an increase in GM ($/ha) with increasing rate of P, up to 16 kgP/ha only. Increasing P rate from 16 to 32 kgP/ha resulted in a decrease of GM of $39 /ha and $26 /ha at Peebinga and Loxton respectively.

Table 4: Gross margin analysis for the two sites

	P rate (kgP/ha)	**0**	**4**	**8**	**16**	**32**
	Fert cost ($/ha)	0	12	24	48	96
Peebinga	Yield (kg/ha)	380	440	470	530	550
	Fert cost c/kg DM	0.00	2.73	5.11	9.06	17.45
	Gross income @ 44c/kg hay	167.2	193.6	206.8	233.2	242
	Gross margin$/ha	**167.2**	**181.6**	**182.8**	**185.2**	**146**
Loxton	Yield (kg/ha)	330	610	700	1070	1120
	Fert cost/kg DM	0.00	1.97	3.43	4.49	8.57
	Gross income @ 44c/kg hay	145.2	268.4	308	470.8	492.8
	Gross margin$/ha	**145.2**	**256.4**	**284**	**422.8**	**396.8**

Conclusion

Our results show that there are productivity gains from applying P fertilisers when sowing vetch on soils with low P reserves. Application of 32 units of P resulted in shoot DM increases of 239% and 45% at Loxton and Peebinga, respectively. However, P applications need to be matched against expected productivity gains for different soil types and rainfall regions to make sure that the fertiliser applications are economically justifiable. The total number of nodules per plant also increased by 363% and 137% at Loxton and Peebinga, respectively, when 32 units of P were added. The results also show that deep placement of P is beneficial to early and late DM production, but can set back nodulation as the plants appear to need the P upfront. P plays a key role in the symbiotic N fixation process by increasing shoot and root growth.

The presence of P decreases the time needed for developing nodules to become active and to benefit the host legume; increases the number and size of nodules; the amount of N assimilated per unit weight of nodules; and the percent and total amount of N in the harvested portion of the host legume (Armstrong, 1999). Improved nodulation and dry matter production can result in significant amounts of nitrogen returned back into the soil and also improved levels of soil organic matter and microbial activity. Cereal yields following vetch are usually at least 30 to 50% higher than in continuous cropping cereals (Unkovich et al 1997). This inclusion of vetch in the rotation is highly beneficial in low rainfall mixed farming systems, where management is focussed on the complementarity of cropping and livestock production to achieve resilience in farming enterprises.

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