The effect of fertiliser placement and row spacing on plant establishment and grain yield of three broad leaf (*Lupinus albus*) and three narrow leaf (*Lupinus angustifolius*) lupin varieties

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Abstract
Lupin agronomy experiments were established to investigate the effects of row spacing and banding starter fertiliser at sowing on crop establishment and grain yield of lupins. The experiments were conducted at Merriwagga in central west NSW in 2011, 2012 and 2013. Treatments included variety, three row spaces of 25, 50 and 75 cm targeting 45 plants/m^2 and starter fertiliser banded at sowing using the rates of zero and 60 kg/ha. The banding of 60 kg/ha of starter fertiliser with the seed at sowing significantly ($p>0.05$) reduced established plant number of all varieties in each year. The largest reduction in established plant number (63%) occurred at the wider row spacing of 75 cm in 2012. The concentrated amounts of fertiliser in the wider rows combined with intra-row crop competition reduced established plant numbers more than in the narrower row spacing of 25 cm. There was no increase in grain yield with the application of starter fertiliser in two of the three years at this site. As row spacing increased from 25 cm to 75 cm, grain yield decreased by 1.02 t/ha in 2011 to as little as 0.15t/ha in 2012. Averaged across years, grain yield decreased by 29% as row spacing increased from 25 cm out to 75 cm. *L. albus* was generally higher yielding than *L. angustifolius* in each of the three years at this site. In this environment the application of between 5.5 and 7.2 kg/ha of phosphorus banded with the seed has been shown to reduce crop establishment and grain yield, especially at the wider row spacing.

Key words
Phosphorous toxicity, row spacing, crop establishment, fertiliser banded

Introduction
Phosphorus (P) is an essential nutrient for the growth of agricultural crops in south eastern Australia. P is a non-renewable resource and often limits crop production unless supplied as fertiliser (Lambers et. al., 2006). The management of soil P and input of P as fertiliser is important for early crop growth and development.

Lupin spp are able to take up phosphorous from the soil via vesicular-arbuscular (VA) endophytes in the form of mycorrhizal roots (Trinick, 1976). Trinick (1976) found that the addition of small amounts of phosphorous (10 µg P/g soil) limited VA formation on the roots and at levels as high as 100 µg P/g soil VA infection was absent. White lupin (*Lupinus albus* L.) has the ability to develop proteoid root systems to extract P from the soil, even in P deficient situations. Keerthisinghe et al. (1998) found that proteoid root formation was suppressed at concentrations of 25 µg P/g soil. Supporting these findings, grower observation and anecdotal evidence from western NSW reported crop establishment issues when P fertiliser was applied with the lupin seed at sowing.

The shift in farming practice from mixed farm enterprises to continuous cropping has led to the development of diverse rotations of which pulse crops are an integral component. In the Western region of the southern NSW cropping zone, pulse crops account for 25% of the cropping area, and some 15% of this is lupins (Pers. Comm., Barry Haskins, 2015). The cost of fertiliser is a significant one for growers involved in crop production. The question then is can we manipulate the row spacing of the lupin crop or the amount of starter fertiliser applied at sowing without reducing grain yields? This paper reports on three field experiments from the Variety Specific Agronomy Packages Project conducted between 2011 and 2013 at Merriwagga in Western NSW. The experiments were investigating the impact of row spacing and fertiliser placement on lupin crop establishment and grain yield.

Materials and Methods

Field experiments were conducted on the Muirhead's property "Palomar" at Merriwagga the soil type is a red sandy loam, pH was slightly acidic ranging from 5.3 to 5.7 in $CaCl_2$. Site description and treatments are listed in Table 1.

Table 1. Experimental treatments of three lupin trials at Merriwagga in 2011, 2012 and 2013.

Year	Varieties	Sow date	Colwell P mg/kg	Fertilser rate	Row Space cm	Herbicide
2011	Kiev Mutant, Rosetta, Luxor, Mandelup, Jenabillup, PBA Gunyidi	21 April	20	0 and 60kg/ha Superfect	25,50,75	Roundup CT 1.5L/ ha + Stomp 1.2L/ ha+0.7kg Terbyne
2012	Kiev Mutant, Rosetta, Luxor, Mandelup, Jenabillup, Wallan 2333	21 April	32	0 and 60kg/ha Granulock	25,50,75	2L/ha Roundup DST + 900g/ha Simazine
2013	Kiev Mutant, Rosetta, Luxor, Mandelup, Jenabillup, Wallan 2333	30 April	39	0 and 60kg/ha Granulock	25,50,75	1L/ha Roundup CT+1kg/ha Terbyne

Note: Granulock 15 (14.3N, 12P,10.5S), Superfect (0N, 8.8P, 11S, 19.1Ca)

The starting seasonal conditions in 2011 and 2012 were similar with very wet summers (150 mm and 240 mm respectively) leading to good moisture conditions at sowing. Growing season rainfall (GSR, April – October) in 2011 and 2012 was 137 mm and 79 mm respectively. In contrast to the first two seasons, 2013 was a drier summer (60 mm) and sowing was into marginal moisture with a GSR of 187 mm. The long term average GSR for Merriwagga is 193 mm. Varieties remained consistent throughout the trials; however PBA Gunyidi was used in 2011 and replaced with Wallan_2333. The trials were sown with a cone seeder set up with Morris contour drill tines (12 mm knife point and press wheels) with a single shoot. The target plant population was 45 plants/m^2. Starter fertiliser (Superfect in 2011 and Granulock 15 in 2012 and 2013) was applied with the seed at 60 kg/ha regardless of row spacing, therefore there was more fertiliser in the wide row space plots compared with the narrower row spacing.

Results

Crop establishment

As row spacing increased from 25 to 75 cm there was a significant ($p=<0.05$) decrease in crop establishment (Table 2). Established plant numbers were significantly ($p=<0.05$) lower when fertiliser was applied with the seed in the first two years (Table 2). There was a 67% reduction in established plant numbers in 2011and a 31% reduction in 2012 when fertiliser was banded with the seed. There was no difference in 2013. There was no significant difference in crop establishment between varieties.

Table 2. Lupin plant establishment (plants/m2) at Merriwagga

Row space (cm)	Fertiliser	2011	2012	2013
25		24	61	52
50		18	43	39
75		11	39	33
lsd		4.1	5.4	4.3
	Zero	27	56	
	Plus	8	39	
lsd		2.8	2.0	

Grain yield

There was no significant difference (*p=<0.05*) in grain yield averaged across the six varieties from row spacing, apart from 2011 where the narrow spacing of 25 cm was significantly higher (Table 3). The yield potential of lupins declined in each year as row spacing was pushed to 75 cm.

Table 3. Effect of row spacing on lupin grain yield (t/ha) at Merriwagga

Row spacing	2011	2.012	2.013
25	2.28	1.29	1.15
50	1.81	1.30	1.26
75	1.26	1.15	1.05
lsd	201	ns	ns

There was a significant interaction (*p=<0.05*) between fertiliser application and row spacing on grain yield

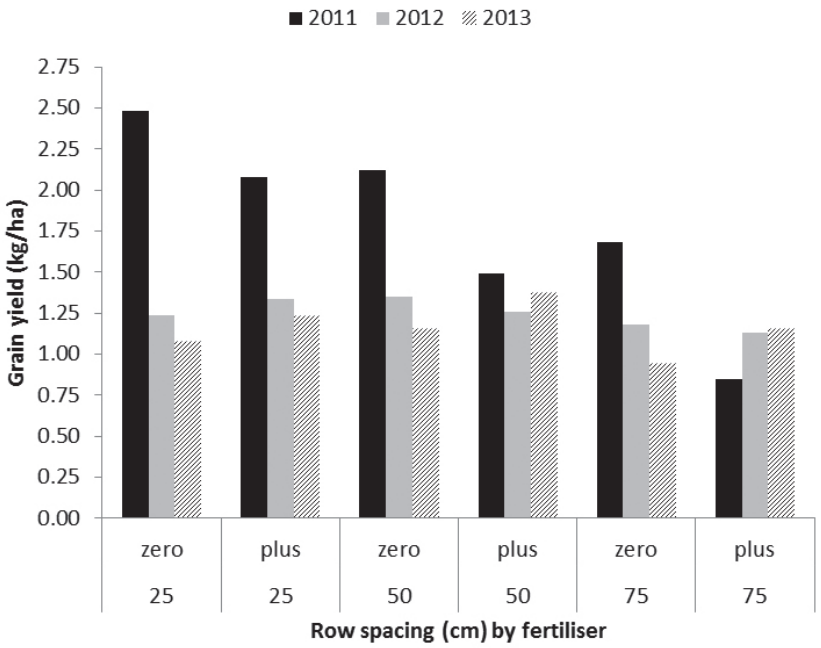

Figure 1. The effect of row spacing and fertiliser application on Lupin Grain yield (t/ha) at Merriwagga in 2011(lsd 0.204), 2012 (lsd 0.206) and 2013 (ns).

The application of starter fertiliser decreased grain yield in 2011 and increased yield in 2013. There was no significant effect in 2012 (Table 4). The addition of starter fertiliser in 2011 significantly reduced crop establishment numbers and this may have confounded the resulting grain yields.

Table 4. Lupin grain yield (t/ha) averaged across varieties, row spacing and fertiliser application rate at Merriwagga

Fertiliser	2011	2012	2013
Zero	2.09	1.26	1.06
Plus	1.47	1.25	1.25
Lsd	0.08	ns	0.14

There was a significant difference (p=<0.05) in grain yield between varieties in all years (Table 5). The broad leafed Albus varieties generally out yielded the narrow leaf Angustifolius varieties at this site.

Table 5. Grain yield (t/ha) of lupin varieties at Merriwagga

Genotype	2011	2012	2013
Kiev Mutant	1.75	1.35	1.33
Luxor	1.85	1.29	1.57
Rosetta	1.68	1.20	1.62
Mandelup	1.88	1.12	0.60
Jenabillup	1.80	1.17	0.89
PBA Gunyidi	1.73		
Wallan 2333		1.36	0.91
PBA Barlock			
lsd	0.15	0.12	0.23

Conclusion

As row spacing increased crop establishment numbers decreased in all years. The concentration of fertiliser at 75 cm row spacing's reduced crop establishment numbers in all years, possibly as a result of intra row competition and the higher rates of fertiliser applied in-row to maintain the rate of 60 kg/ha across all row spacing's. The application of starter fertiliser banded with the seed reduced lupin crop establishment numbers in two of the three years. Trial results from the project, **'**Expanding the Use of Pulses in South-Eastern Australia (DAV00113)' showed that banding 20kg/ha of P with chickpea seed significantly reduced crop establishment, whilst separating the fertiliser and seed also reduced crop establishment when the rate reached 30kg/ha of P.

Applying starter fertiliser at sowing to lupins had a mixed effect on the grain yield of lupins. There is not enough evidence from these trials to conclude if there was a consistent positive or negative response in grain yield. There was a significant reduction in grain yield in the first year and no difference in 2012 and a significant increase in 2013. What is apparent from these trials is that in an optimum season under favourable conditions, row spaces of 75 cm have a lower yield potential than narrower rows of 25 and 50 cm. The grain yield in these trials is impacted by the reduction in established plant numbers, especially in 2011.

The interaction between row spacing and fertiliser application was only recorded in 2011 and 2012, both seasons had drier winters. There was no interaction in 2013 possibly due to the wet period in June and July after seeding. There was a significant yield reduction as row spacing increased from 25 to 75cm in 2013 and a general trend of lower yields in each of the other seasons at 75 cm. From these trial results grain yield is compromised when row spacing of lupins exceeds 50 cm.

The results from these trials over three years suggest that the banding of fertiliser with the seed at sowing significantly reduces plant establishment and can have a detrimental impact on grain yield. Applying zero fertiliser did not have an impact on crop establishment; however the long term sustainability of the cropping system could be placed under pressure if P is removed from the rotation even for one season.

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