The net contributions of fixed N by crop legumes in low rainfall farming systems

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Abstract
The inclusion of grain legume crops in low rainfall farming systems of south-eastern Australia can improve subsequent cereal crop productivity where nitrogen (N) is a limiting factor. However, little is known about either the productivity or the capacity of crop legumes to contribute N in this low rainfall environment. Over three seasons (2013-2015) break crop comparison trials were sampled to measure dry matter (DM) production and symbiotic N_2 fixation of chickpea, field pea, lentil, lupin, faba bean and vetch crops grown in the Victorian and South Australian Mallee. On average, shoot DM produced across species and seasons was in the order of 3 – 4 t DM/ha while average grain yields for all species across the three years was around 1 t/ha. Chickpea fixed significantly less shoot N than the other species, which on average fixed ~60 kg N/ha in the above-ground DM across the three seasons. After taking account of the amount of N removed in harvested grain across the three seasons, and including estimates of the likely contributions of fixed N associated with the nodulated roots, 12 of the 15 crop by season combinations were calculated to have provided agronomically significant net inputs of fixed N for the potential benefit of following crops. Therefore it was concluded that legume crops appear to be a viable mechanism to maintain or improve the N fertility of cropping soils in low rainfall Mallee farming systems.

Key Words
Nitrogen input, nitrogen fixation, nitrogen balance, chickpea, field pea, lentil, faba bean, lupin, vetch

Introduction
Farmers are increasingly incorporating grain legume crops in low rainfall (275 – 350 mm annual rainfall) farming systems in the Mallee region of south-eastern Australia to manage biological constraints that have developed following a prolonged period of intensive cropping with cereal species. Recent research within the Mallee region has demonstrated that the inclusion of break crops can increase the productivity of subsequent wheat crops by one tonne per hectare, which is of similar magnitude to break benefits observed in higher rainfall regions within southern Australia and elsewhere in the world (McBeath et al, 2015; Angus et al 2015). McBeath et al (2015) primarily attributed the break benefit to beneficial effects on the cycling and supply of nutrients and suggested that the inclusion of break crops is likely to improve subsequent cereal production where nitrogen (N) is a factor limiting productivity in low-rainfall, semi-arid environments such as the Mallee.

Despite the willingness of farmers to incorporate legume grain crops in Mallee crop rotations, there is little data available which compares productivity and N_2 fixation capacity of pulse crops in low rainfall environments of southern Australia. In this paper, we report the amounts of N_2 fixed by a range of pulse crops obtained from judicious sampling of treatments within trials conducted in the Victorian and South Australian Mallee between 2013 and 2015, and provide estimates of the net inputs of fixed N for the potential benefit of following crops. It is important that this information is available to assist farmers to improve select break crops which balance short-term profit with long term productivity and sustainability.

Methods
Replicated small plot trials comparing a range of legume grain crop species (field pea, chickpea, lentil, faba bean, vetch and narrow-leaf lupin) and varieties were conducted in the low rainfall Mallee region at sites near Mildura (Victoria) in 2013 and 2014 and near Loxton (South Australia) in 2015. Each of these trials were conducted on a Calcarosol with a sandy loam - loam textured soil types which are considered the premium soil type for crop production within the region. All three trials were sown into a moist seedbed in the first week of May in each season with agronomy optimized for each species. Immediately prior to sowing, each treatment was inoculated with a specific strain of commercial peat rhizobial inoculant by placing a small amount of each inoculant in the plastic bag containing the seed and shaking and rubbing each bag to obtain contact between the seed and inoculant. Growing season rainfall varied between 130 and 145 mm in each season which is less than the long term average of approximately 175 mm, although sub soil

moisture was present prior to sowing at Mildura in 2014 and Loxton in 2015. The Loxton trial was impacted by both frost and heat in 2015 which is likely to have impacted the grain yields.

Shoot biomass was sampled from selected treatments in each trial by taking four quadrate (0.6 x 0.4 m) cuts from the middle four rows of the 6 row plots in each treatment (Table 1). Sampling was undertaken when each treatment reached maximum seasonal biomass. The ^{15}N natural abundance technique was utilised to estimate the proportion of the plant N derived from atmospheric N_2 (%Ndfa) by legume treatments using unfertilised canola sampled at the same time as the non-fixing reference (Unkovich et al 2008). All samples were dried at 70°C before being weighed to calculate total dry matter (DM) production. Dried plant samples were analysed for % N and ^{15}N abundance using a 20-20 stable isotope mass spectrometer (Europa Scientific, Crewe, UK). Nitrogen fixed in the shoot DM was then determined with the following equation:

Shoot N fixed = (legume shoot N) x (%Ndfa/100) Equation [1]
Where shoot N = (shoot DM) x (%N/100)

The shoot-based measures of fixed N calculated using Equation [1] were adjusted to include estimates of the contribution of below-ground legume associated with nodulated roots using the 'root-factors' (Table 1) recommended by Unkovich et al. (2010):

Total N fixed = (shoot N fixed) x (root-factor) Equation [2]

Grain yields of all treatments were measured using a mechanical plot harvester. Grain N content (Table 1) for each species were obtained from existing data sets and were used to estimate grain N removal. The net inputs of fixed N remaining in legume residues and roots were calculated as:

Net input of fixed N = (total N fixed) – (grain N removed) Equation [3]

Table 1. Varieties selected to represent each crop species from low break crop comparison trials at Mildura (2013 and 2014) and Loxton (2015) and the root factor and percent grain nitrogen values used to determine net input of fixed N for each crop species.

Crop	**Variety**			**Root factor**[d]	**Grain N%**
	2013	2014	2015		
Chickpea[a]	PBA Striker	PBA Striker	PBA Striker	2.06	3.8
Field Pea	PBA Wharton	PBA Wharton	PBA Wharton	1.46	4.3
Lentil[b]	-	PBA Bolt	PBA Hurricane	1.48	4.46
Lupin	Mandelup	Mandelup	PBA Barlock	1.33	5.6
Faba Bean	Farah	Farah	PBA Samira	1.52	4.3
Vetch[c]	Rasina	Rasina	Rasina	1.56	5.04

[a]Biomass data from chickpea in 2013 omitted as sampling possibly occurred prior to peak biomass
[b]No production data from lentil treatment were available in 2013 due to herbicide damage to the crop
[c]Vetch was sampled from an adjacent trial site in 2014 and grain yield was not measured
[d]Root factors recommended by Unkovich et al. (2010)

Results and discussion

The productivity of each grain legume crop across the three sites and seasons is shown in Table 2. The average shoot DM accumulated across all treatments and season was generally between 3 – 4 t/ha per hectare with field pea producing the greatest biomass in all seasons. Average grain yield of the legume species was approximately 1 t/ha across all sites and seasons. This is approximately two thirds of what is considered the region's long-term average grain yield of wheat (1.6 t/ha).

There was significant variation in the amounts of shoot N fixed between chickpea and other grain legume species (Table 3) with significantly less N fixed in the shoot DM than all other crops in 2014 and 2015. Nitrogen fixed per tonne of shoot DM was also considerably lower for chickpea (<11 kg N/t DM) than all other crop species (13-22 kg N/t DM; Table 3). Low shoot N_2 fixation by chickpea relative to other crop species has been reported elsewhere. Previous meta-analyses of average shoot N fixed data collated for chickpea from other regions of Australia was 10.7 kg N/t DM (Unkovich et al, 2010) which is consistent with the findings from the current study. In our analysis, chickpea %Ndfa was approximately 50% which was significantly lower than for all other crops (%Ndfa of 61 – 83%, Table 3).

Table 2. Productivity (shoot dry matter and grain yield) of grain legume crops grown in the low rainfall zone at Mildura (Victoria) in 2013 and 2014 and Loxton (South Australian) in 2015.

Crop	Shoot DM (t/ha)			Grain Yield (t/ha)		
	2013	2014	2015	2013	2014	2015
Chickpea	-	4.2	2.7	0.9	1.6	0.6
Field Pea	2.5	5.8	3.6	1.1	2.3	0.6
Lentil	-	4.9	3.3	-	1.5	1.0
Lupin	2.6	4.1	2.6	1.0	1.2	0.7
Faba Bean	2.0	4.8	3.0	0.5	1.4	0.8
Vetch	0.8	4.5 [a]	3.4	0.4	-	0.8
LSD ($P<0.05$)	0.7	1.1	0.6	0.2	0.5	0.1

[a]Data not included in statistical analysis as samples were collected from an adjacent trial site. Grain yield was not measured.

The amounts of shoot N fixed was less variable between the other crop species (Table 3) and variation was generally greater between seasons than between species within a season. Averaged across all species, the amounts of N fixed per tonne of shoot DM was 16.3 kg N/t DM, which was somewhat lower than 21.3 kg N/t DM reported by Unkovich et al, (2010) for field pea and faba bean, but higher than the 14.2 kg N/t DM for lupin. In this study, field pea had significantly lower rates of N_2 fixation per tonne of shoot DM than all other species with the exception of chickpea in 2015. However, the amounts of shoot N fixed calculated on a per hectare basis by field peas ended up being similar to faba bean because of its greater biomass production. Due to the importance of field pea as a break crop in the southern Australia low rainfall zone, further research is warranted to assess why N_2 fixation per tonne of DM by field pea seems low in this region.

Table 3. Estimates of the proportion (%NDFa) and amounts of shoot N fixed by grain legume crops grown in the low rainfall zone at Mildura (Victoria) in 2013 and 2014 and Loxton (South Australia) in 2015.

Crop	%NDFa			Shoot N fixed (kg N/ha)			Shoot N fixed (kg N/t DM)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Chickpea	-	51.4	48.4	-	88	25	-	10.9	9.2
Field Pea	73.9	81.5	66.1	39	132	47	15.2	18.6	13.1
Lentil	-	82.8	70.3	-	107	50	-	18.2	15.3
Lupin	75.2	78.2	65.9	50	101	46	19.0	19.8	17.7
Faba Bean	73.9	77.9	61.4	40	133	48	19.6	21.6	16.0
Vetch	64.3	74.2 [a]	68.6	18	[a]123	56	21.8	[a]20	16.4
LSD ($P<0.05$)	11.5	5.3	8.8	13	23	9	2.9	1.8	1.7

[a]Data not included in statistical analysis as samples were collected from an adjacent trial site

Figure 1 provides comparisons of the net inputs of fixed N remaining following grain harvest have been calculated for each of the six legume crops across each the three seasons, where the shoot-based measures of N_2 fixation have been adjusted to include estimates of the additional fixed N associated with the nodulated roots (Unkovich et al 2010). The data suggested that when fixed N in both plant shoots and nodulated roots were considered, all crops with the exception of vetch, field pea and lupin grown in 2013 were likely to have contributed agronomically useful inputs (>10 kg/ha) of fixed N to Mallee farming systems following grain harvest.

A linear regression was computed for all data points shown in Figure 1. There was a significant relationship between total N fixed and the net N input of fixed N for all crop and season combination ($R^2 = 0.91$). The legume crops would on average make a positive N contribution when approximately 23 kg/ha of N was fixed. Evans et al (2001) reported comparable, but slightly higher values for field pea (35 kg N/ha), lupin (30 kg N/ha) and chickpea (49 kg N/ha). Their analysis concluded that legume crops were highly likely have a positive net N balance once total N fixed reaches 70 kg N/ha. In our analysis, the 95% confidence interval for a positive net N balance was 39 kg/ha of total N fixed, and reflects the much lower yield potential in the Mallee than the higher rainfall environments considered by Evans et al (2001).

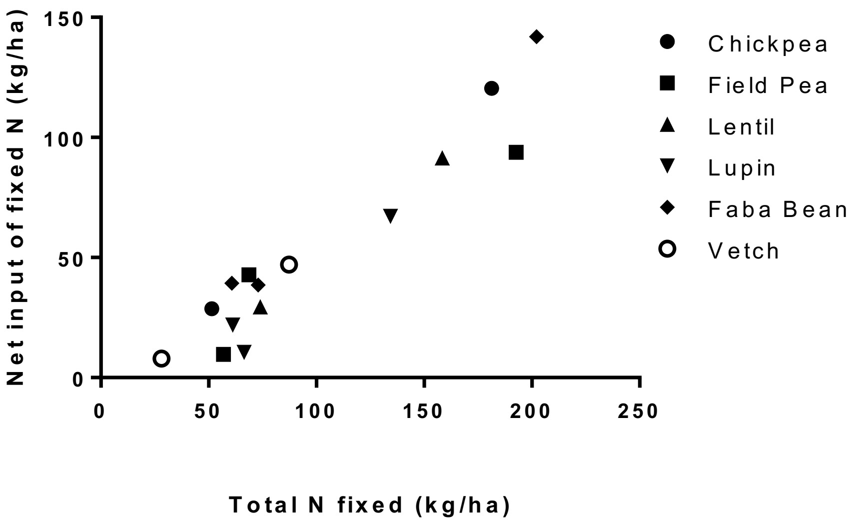

Figure 1. Relationship between total N fixed (shoot + root) and net inputs of fixed N following grain harvest for various legume crops grown in the low rainfall zone at Mildura (Victoria) in 2013 and 2014 and Loxton (South Australia) in 2015.

Conclusion

The data generated from the current three-year study has highlighted that grain legumes have the capacity to positively contribute to the N balance of low rainfall farming systems. The average net input of fixed N across all legume crops and seasons was ~50 kg N/ha; however, the average for all crops varied between 17 and 103 kg N/ha between seasons. Based on an average cereal yield of 1.6 t/ha and N removal of 32 kg N/ha per year during the cereal phase, soil N reserves could perhaps be maintained if two cereal crops were grown for every grain legume phase in this environment. Such intensity would present challenges both for farm business risk and profitability in the low rainfall zone and could also lead to agronomic issues such as legume disease build up and broadleaf weed problems arising from such frequent phases of legume crops in paddocks. Therefore, further research is required that investigates a wider range of options for farmers to maintain the N balance and soil fertility in the low rainfall regions. In addition to legume crops harvested for grain, such options could include pastures, legume crops sown for forage or manuring, and N fertiliser strategies. The interaction between these N management strategies could be explored with the use of simulation modelling to determine the optimum combinations and intensity of break crops to sustainably manage nitrogen in low rainfall farming systems.

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