Results and Observations from Commercial Legume Crops and Pasture – 2015

Aim

Commercial legume crops and pasture paddocks were surveyed to assist in identifying factors affecting nitrogen fixation and plant growth. N_2 fixation and its potential contribution to increasing total soil N were estimated at 16 commercial sites.

Background

Legume growth (biomass production) is the primary regulator of N fixation. Previous studies have identified large variation in the amounts of N fixed for every tonne of above-ground dry matter (DM) produced by crop and pasture legumes, ranging from < 10 to 250 kg N/ha per year (Peoples et al 2012, 2014, 2015). The 'rule-of-thumb' figure target range widely used to estimate the amount of N fixed by legumes is about 20 - 25 kg of shoot N per tonne of above-ground DM. The reasons for variation in the proportion of legume-N derived from atmospheric N_2 fixed (%Ndfa) by commercial paddocks in south-eastern Australia needs to be better understood.

Commercial crops sown in 2015 in south-eastern NSW, southern Victorian, southeastern SA and the northern Midlands of Tasmania were monitored to pinpoint factors influencing N fixation and management opportunities to improve N_2 fixation by legume species. Analysis of soil and plant measurements and observations taken from the commercial sites focused on factors affecting the efficiency of N fixation, and in particular effectiveness of nodulation. Nodulation was raised by industry as an area of concern during early consultation by the project team.

Climate

Low rainfall affected above-ground biomass production and yield at all sites. Crops were moisture stressed during the critical flowering and grain filling period of September-October, which included eight continuous weeks of no effective rainfall and wide temperature fluctuations. These extreme conditions are considered the primary factors that determined biomass production, N_2 fixation and grain yield.

Rainfall in the spring, summer and autumn periods of the 2014 winter cropping season was well below average for the SA, Victorian and Tasmanian sites included in this study. All 2015 sites in these states were sown with very low soil moisture reserves. Growing season rainfall (April – October, inclusive) in 2015 was also below average at all except the NSW sites. Grower records (Table 1) indicate that 2015 rainfall for this period at the SA and SW Victoria sites were less than 65% of the long-term average, but the two Tasmanian sites at Avoca and Campbell Town recorded less than about 30%. The Campbell Town crop did not progress to grain fill and was cut for hay.

Soil moisture reserves were adequate for all NSW sites at time of sowing and conditions were near ideal for crop growth until August when the above-average winter rainfall caused waterlogging at some sites. Despite NSW growers reporting growing season rainfall 106 - 123% above average, biomass production and grain yield was also reduced by extremely dry conditions in September and October, with no effective rainfall from early September.

Methods

Fifteen growers in NSW, Victoria, SA and Tasmania nominated paddocks that were to be sown to legumes in 2015 for the on-farm component of this project. One farmer nominated 2 paddocks. An area of 1 ha, not likely to suffer obvious growth constraints, e.g. low lying, flood-prone areas were avoided, of each paddock was selected. Soils were sampled in February at depths of 0-10 cm and 10-20 cm and tested for phosphorus levels (Colwell), pH (Water and $CaCl_2$ methods), electrical conductivity, Aluminum (KCL extraction) and exchangeable cations through Nutrient Advantage Laboratories.

A total of 15 legume crops (12 faba bean, 2 narrow-leaf lupin crops and 1 field pea crop) and 1 sub clover pasture were assessed 2-3 months post-emergence for effectiveness of nodulation using the Colombia protocol (Anon 1991). Plants with intact root systems were collected at random from the designated areas and scored for nodulation. Scores were allocated for (1) plant growth and vigour, (2) nodule number, (3) nodule position, (4) nodule colour, and (5) nodule appearance; with '25' the maximum possible total score.

Crop and pasture samples were collected by mid-October from the designated areas in each paddock at a time considered to coincide with peak biomass production and therefore N accumulation. Using the ^{15}N natural abundance technique, the amount of N accumulated in the shoots of the legume plants was measured and compared with the amount in non-legume plants growing nearby (e.g. in-crop grass weeds) to estimate the proportion of legume N coming from the soil N pool and that derived from the atmosphere (%Ndfa). The amount of legume N fixed was then calculated as a percentage of the total N accumulated by the legumes. The %Ndfa value is a measure of the dependence of the legume on fixed N (Evans et al 1989):

Amount of N_2 fixed over the growing season (kg N/ha)
= total legume N x %Ndfa/100 (Peoples et al 2015)

Results and Discussion

Although the results from these demonstration sites cannot be statistically analysed, the information and observations from the commercial paddocks suggest that the main factors contributing to variation in the amounts of N fixed by the crop and pasture legumes in this study are:

1. The effect of soil acidity on nodulation
2. Growing season rainfall
3. Sowing time
4. Soil mineral N

Table 1. A summary of site details and crop related information for sites monitored in 2015

Site/Crop	Locality	Inoculant formula	Soil pH ($CaCl_2$) (0-10)	Soil pH ($CaCl_2$) (10-20)	Nodulation Score**	Growing season rainfall Apr-Oct (mm) (Est. long term av. & percent of long-term av.in brackets)
SA - VIC Border						
1. Faba	Frances	peat slurry	5.2	5	21	206 (370-56%)
2. Faba	Kybybolite	peat slurry – 1.5 rate	4.5	4.7	15	238 (370-65%)
VIC – South West						
3. Faba	Wickliffe	granular	5.8	5.9	15	239 (400-60%)
4. Faba	Narrapumelap	peat slurry	6.5	5.5	20	267 (405-65%)
5. Faba	Willaura	peat slurry (CS#)	5.8	5.4	24	182 (320-57%)
6. Faba	Willaura	peat slurry (WS#)	5.3	4.8	23	182 (320-57%)
7. Sub Clover$^{\alpha}$	Lake Bolac	pre-inoculated	5.1	4.8	22	258 (405-64%)
VIC - South Central						
8. Faba	Darlington	granular	5.2	5.4	23	270 (405-45%)
9. Faba	Lismore	peat slurry	4.7	4.8	17	340 (405-84%)
10.Faba	Inverleigh	granular	5.1	5.6	20	239 (320-76%)
NSW – South West						
11.Faba	Holbrook	peat slurry	4.6	4.1	17	570 (460-123%)
12.Faba	Henty west	peat slurry	5.6	4.5	24	290 (360 - 81%)
13.Lupin	Henty east	freeze dried	5.4	4.3	24	379 (360-106%)
14.Lupin	Mangoplah	peat slurry	5.9	5.2	24	390 (360-109%)
TAS - East Midlands						
15.Faba	Avoca	peat slurry	5.4	4.9	25	123 (390 - 32%)
TAS - Central Midlands						
16.Field pea	Campbell Town	peat slurry	5.8	5.4	23	30 (295 - 10%)

* Lime was applied in recent years at all sites except (Ky), standard practice was surface application with nil or minimal incorporation.

** Nodulation Score: Maximum = 25 (Columbia protocol – Anon, 1991)

CS# - sown on canola stubble (Crop 5), WS# - sown on wheat stubble (Crop 6).

Soil pH and nodulation

The nodulation scores for the monitored commercial crops and pasture are presented in Table 1. The scores ranged from 15-25 and provided an indication of the effectiveness of nodulation and nitrogen fixation potential of the legume (Anon 1991).

A score of:

- 20 – 25: indicates effective nodulation; good nitrogen fixation potential.
- 15 – 19: nodulation is less effective and fixation potential is reduced. The inoculation process or environmental conditions may have caused the sub-optimal result.
- 0 – 14: unsatisfactory nodulation, possibly because an inappropriate strain of rhizobia had been used or the conditions at the site affected the nodulation process.

The four sites returning a nodulation score of less than 20 (Sites 2, 4, 9 and 11) were followed up to identify the reasons for sub-optimal nodulation. All these sites were sown to faba bean. Worth noting is that the 0-10 cm (topsoil) pH_{Ca} test results for Crops 2 (SA), 9 (VIC) and 11 (NSW) were all below 5.0 (4.5, 4.7 and 4.6, respectively).

The link between nodulation score and topsoil pH is shown in Figure 1. Analysis of the nodulation scores for faba bean crops and pH of 0–10 cm soil samples showed a strong correlation (r^2=0.82) where low pH was associated with poor nodulation and higher pH indicative of better nodulation. This indicates that nodulation is affected by soil pH, which is to be expected given that survival of the strain of rhizobia specific for faba bean (Group F) is compromised at pH below 5.0 (Drew et al 2012).

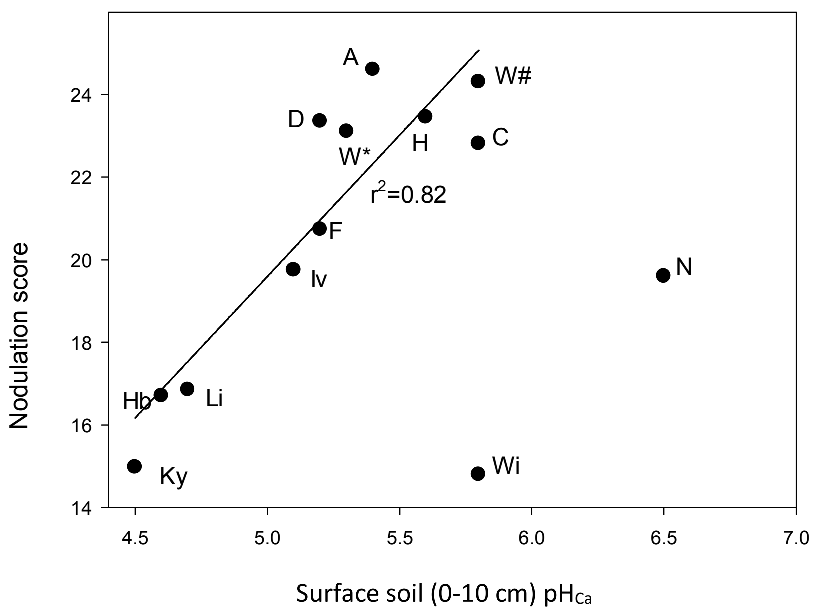

Figure 1. The effect of topsoil pH (0-10cm) on nodulation of faba bean at commercial sites* across the south-eastern Australian high rainfall zone in 2015

Sites are Kybybolite, S.A. (Ky), Holbrook, NSW (Hb), Lismore, Vic (Li), Inverleigh, Vic (Iv), Frances, SA (F), Darlington, Vic (D), Willaura, Vic (W) and Henty, NSW (H). W = after wheat, W# = after canola, Wickliffe, Vic (Wi) and Narrapumelap, Vic (N)

Note that the two outliers in Figure 1, Wi (Site 3 - Wickliffe) and N (Site 4– Narrapumelap) had nodulation scores of 15 and 20, respectively. These sites were not included in the

analysis as the relatively poor nodulation can be explained by reasons other than the pH value of the 0-10 cm soil sample.
The poor nodulation score at Site 3 (Wi) was reportedly the result of the granular inoculant bridging in the seeder box, which caused poor distribution of the inoculant and very patchy nodulation in the crop. The marginal nodulation at Site 4 is suspected to have been the result of stratified pH in the topsoil where lime had been applied to the surface and not incorporated. This was the case for other faba bean paddocks inspected at Narrapumelap, but not reported here. While a mixed 0-10 cm topsoil sample indicated pH above 5.0, the pH of surface layers tested separately was below 4.0 at a depth of 5 cm, the approximate faba bean sowing depth. The resulting pH stratification and its impact on faba bean nodulation is presented in a separate project report available from the authors.

The impact of stratified pH of the topsoil on faba bean nodulation highlights the need for paddock selection and forward planning when sowing faba bean into acid soils:

- Group F rhizobia survival and faba bean nodulation and root growth is compromised in soils with pH_{Ca} < 5.0 (the recommended pH for faba beans is > 5.2).
- Lime applied to the soil surface moves very slowly down the soil profile. Use of fine grade lime, incorporated to a depth of 10 cm, is recommended in order to optimise the rate of reaction and therefore effectiveness of the applied lime.

Nitrogen fixation

The estimates of the proportion of legume-N derived from atmospheric N_2 (%Ndfa), the amount of shoot N fixed per tonne of shoot dry matter (kg N/t shoot DM) and the amount of shoot N fixed per hectare (kg N/ha) by the 2015 crops and pasture are shown in Table 2.

The estimated % Ndfa values range from 42-82%, while the estimated amount of shoot N fixed ranged from 10-21 kg N/t shoot DM. Based on previous studies conducted in south-eastern Australia, Peoples et al (2012) proposed the benchmark %Ndfa values indicative of effective N fixation are > 65% (considered in the 'high'), and a target range of about 20 - 25 kg N/t shoot DM for the amount of shoot N fixed.

Environmental conditions and management were major factors affecting N_2 fixation and N accumulation by the legumes. These included soil constraints (pH), rainfall, sowing time, effectiveness of the host-rhizobia combination and the availability of alternative N sources (Peoples et al 2001; and Evans et al 1989).

<u>Seasonal rainfall</u>

The dry conditions experienced at Victorian, South Australian and Tasmanian sites are considered to have been the primary factors determining biomass production and N fixation values. The exception to this are the South West VIC sites where early sowing time and superior nodulation scores (24 and 23) at Sites 5 and 6, respectively, may have contributed to greater %Ndfa values (74 and 64 %) and biomass production (6.2 and 6.5 t DM/ha) compared with nearby Site 4, which had a nodulation score of 20, 57 %Ndfa and 4.9 t DM/ha.

Table 2. Site details, crop information, the estimated proportion (%Ndfa) and amounts of foliage N fixed by legumes at the 2015 commercial sites

Site / Crop	*Paddock history	Locality	Growing season rainfall (mm)	Sowing date	N fert (kg/ha)	Nodulation score	Legume biomass (t/ha)	%Ndfa	Shoot N fixed – kg N/t shoot DM (kg N/ha$^{\alpha}$)	Grain yield (t/ha)
SA – VIC Border										
1.Faba	WWC + 5yrs crop	Frances	206	22 May	0	21	3.3	43	13 (45$^{\alpha}$)	1.0
2.Faba	BWBCBWCW + 2yrs crop	Kybybolite	238	3 May	8	15	4.7	35	11 (60$^{\alpha}$)	1.15
VIC – South west										
3.Faba	WCLWCLWC	Narrapumelap	267	15 May	7	20	4.0	72	19 (75$^{\alpha}$)	0.8
4.Faba	WCWCWCOW + 32 yrs crop	Wickliffe	239	14 May	6.5	15	4.9	57	16 (76$^{\alpha}$)	1.5
5.Faba	CWCWCWCW + 18 yrs crop	Willaura	182	28 April	0	24	6.2	74	15 (92$^{\alpha}$)	1.0
6.Faba	WCWCWCWC + 18 yrs crop	Willaura	182	28 April	0	23	6.5	65	17 (112$^{\alpha}$)	1.0
7.Sub clover	WCWBC + 10yrs crop	Lake Bolac	258	12 April	56	22	0.47#	79	22 (10$^{\alpha}$)	NA
VIC – South central										
8.Faba	WCWWCBWC + 5yrs crop	Darlington	270	18 April	10	23	7.9	48	10 (76$^{\alpha}$)	2.5
9.Faba	CBWL..unknown	Lismore	340	12 May	8	17	3.1	58	15 (46$^{\alpha}$)	1.9
10.Faba	WCWBWCBW + 3yrs crop	Inverleigh	239	20 May	14	20	5.1	42	11 (54$^{\alpha}$)	0.91
NSW – South west										
11.Faba	W …unknown	Holbrook	570	8 May	7	17	4.2	77	21 (87$^{\alpha}$)	1.0
12.Faba	WC ..unknown	Henty west	290	21 April	7	24	6.3	82	19 (119$^{\alpha}$)	1.4
13.Lupin	WCWCWLO + 3yrs crop	Henty east	379	29 April	0	24	5.6	70	20 (112$^{\alpha}$)	1.2
14.Lupin	WWCWL + 7yrs crop	Mangoplah	390	5 May	0	24	6.3	74	19 (117$^{\alpha}$)	1.9
TAS – East Midlands										
15. Faba	BfbWRP	Avoca	123	10 July	0	25	4.2	54	14 (60$^{\alpha}$)	1.25
TAS Central Midlands										
16. Field peas	BBPCpast	Campbell Town	30	15 Aug	18	23	3.0	75	17 (52$^{\alpha}$)	Hay cut

* W – wheat; B – barley; O – oats; C-canola; L – narrow leaf lupins; fb – forage brassicas; P – poppies; R – ryegrass; past – pasture. # Pasture was 10% clover.

Sowing time

The results show a general trend of increased peak biomass production and shoot N accumulation from early sown faba bean crops. Comparing regional sites with effective nodulation, Site 5 at Willaura in SW VIC produced 6.2 t DM biomass/ha and fixed 112 kg shoot N/ha from a 28 April sowing but Site 3 at nearby Narrapumelap produced only 4.0 t DM/ha and 76 kg shoot N/ha from a 15 May sowing date. The proportion of legume N from the atmosphere (%Ndfa) was also higher for the early sown crop with 65% at Site 5 and 57% for Site 3.

The advantage of early sowing on DM production and shoot N fixed is also apparent for sites with effective nodulation in the central region of southern VIC. Site 8 (Darlington) produced 7.9 t DM/ha and fixed 76 kg shoot N/ha from 18 April sowing, compared with 5.1 t DM/ha and 54 kg shoot N/ha from the 20 May sown Site 10 (Inverleigh).

These results are as expected. In general, provided soil moisture is not limiting, most temperate crops produce maximum dry matter when sown early in the recommended sowing window, while soil temperatures are relatively warm. Plant growth rate, nodulation and rhizobia activity slows as temperatures drop. If the aim is to maximize N_2 fixation sow early to achieve higher dry matter production, N_2 fixation rates and crop N concentration (O'Connor et al 1993).

Check Pulse Australia faba bean sowing date recommendations (Anon 2016). Sowing time recommendations are set to balance dry matter production and yield. Sowing too early under ideal growing conditions may result in a bulky crop, an environment that favours fungal diseases and low yield (i.e. low harvest index). The recommended sowing window for rainfall zones of >450 mm is from the 2nd week in May to the 2nd week in June. However, under acid soil conditions the sowing window for >450 mm regions is earlier, from the 1st week in May, and only until the 3rd week in May.

This study highlights the need for more research into sowing dates for pulses grown on acid soils. Field observations showed that subsurface soil acidity checked nodulation, early vigour and dry matter production of faba bean crops and suggest there may be benefits in sowing from mid to late April, particularly in challenging acid soil environments. Experience with crops sensitive to acid soils e.g. lucerne, barley and canola, suggests that early sowing allows the sensitive seedlings to establish, accumulate leaf and develop a robust plant that is more tolerant of the additional cold and waterlogging stresses of winter.

Soil mineral N

With a %Ndfa value of >65% used as an indicator of effective N fixation and 20 - 25 kg N/t shoot DM as a rule-of-thumb target for the amount of foliage N fixed, the variation and some unexpected results shown in Table 2 for faba bean crops at Sites 8, 10 and 11 as well as the pasture at Site 7 need explanation. Previous studies indicate that soil mineral N concentrations above about 50 kg N/ha at sowing suppress legume N_2 fixation. This effect of alternative N sources may provide some answers (Peoples et al 2015; Evans et al 1989). Deep N tests at the commencement of the 2015 season would have provided an indication of the concentration of soil mineral N and helped explain some of the results, but were not able to be done.

Sites 8 and 10

The relatively low N_2 fixation measurements for faba bean crops at Sites 8 and 10 are difficult to explain. Both these sites had a long history of cereal and canola crops, so presumably soil mineral N levels would have been depleted at the commencement of 2015. Although nodulation scores indicated the both bean crops nodulated effectively, and biomass production was reasonable, %Ndfa values of 10% and 11 %, and 48 and 42 kg N/t shoot biomass, respectively, are well below the benchmark levels for % Ndfa and foliage N above.

Perhaps residual mineral N levels carried over from the 2014 crops are a reason for the low levels. Exceptionally dry conditions from August 2014, when approximately 50 kg N/ha was applied to wheat crops at Sites 8 and 10, may have resulted in carryover of some of the N fertiliser and suppressed legume N fixation.

Site 11

Despite very poor nodulation of the faba bean crop at the Holbrook site, explained by soil acidity (Figure 1), the estimated %Ndfa of 21% and shoot N fixation of 21 kg N/t shoot DM suggest that the crop nodulation and N_2 fixation was effective. This was definitely not the case; for this crop and cannot be explained. The crop showed severe N deficiency symptoms in early September, which prompted the grower to topdress the crop with urea in early September, excluding the area sampled for peak biomass in October.

More realistic N fixation estimates would be well below 15% Ndfa and 65 kg N/t shoot DM.

Site 7

The clover samples taken at Site 7 pasture returned the highest values for %Ndfa (22%) and accumulation of shoot N (79 N/ t shoot DM) of all legumes monitored. The N fertiliser applied at sowing (10 kg N/ha) and in late winter (46 kg N/ha) did not suppress N_2 fixation by the clover. This is likely because the pasture was dominated by ryegrass with only 10% clover. Any soil mineral N would have been used by the grasses and therefore is unlikely to have suppressed N_2 fixation by the clover.

Although the results show that the clover plants were very effective in fixing N, the amount of N fixed per hectare was very low (10 kg N/ha) and therefore the legume component of the pasture is likely to have contributed very little atmospherically derived N to the to the soil N pool.

Key Messages and Comments

- The form of inoculant used did not appear to affect nodulation of legumes.
- Nodulation of faba bean is reduced when pH_{Ca} is < 5.0.
- Exceptionally dry conditions were the main factors reducing biomass production and grain yield.
- Sowing time influenced biomass production and N_2 fixation: April sown faba bean crops produced more above-ground biomass and %Ndfa than mid to late May sown crops.

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