18. The Nitrogen Contribution of Pulses in Acidic Soils of the High Rainfall Zone of South Eastern Australia:

Measurements from 2015 - 2017 Commerical Faba Bean Crops

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KEY MESSAGES

- Select crops best adapted to the soil and climatic conditions of your region; faba bean is the pulse crop best adapted to soils prone to waterlogging.
- Avoid soils with acidic subsurface layers and/or shallow topsoil that limit root development and impermeable subsoil that restrict drainage.
- Test soil pH at 5cm intervals to a depth of 20 cm, to detect subsurface acidity.
- Select paddocks at least two years before sowing acid-sensitive crops to allow time for applied lime to react and increase soil pH, if required.
- Sow early in the recommended sowing window for your location, to encourage effective nodulation, early vigour and biomass accumulation before the onset of cold, wet conditions.

Background

This report presents the SA and SW Victorian results from a joint GRDC and NSW Department of Primary Industries project that surveyed 45 commercial pulse crops in southern Victoria, south eastern SA, Tasmania and southern NSW. The project aimed to identify factors limiting N2 fixation and productivity of pulse crops grown on acidic soils in the high rainfall zone (HRZ) Southern Grain production region. The observations on 16 commercial faba bean crops sown in 2015 to 2017, into acidic soils in the Frances region of SA and the Victorian Lake Bolac district, are summarised here.

The study highlights the importance of understanding pulse agronomy and managing the unfavourable conditions facing pulses growing in acidic soils in order to optimise N_2 fixation and yield potential. As one of the participating growers commented:

"… it's clear from what we are seeing we need to pay more attention to soils and agronomy"

In the 2018 MFMG report on this project we discussed the impact of subsurface acidity on nodulation and the importance of lime incorporation to achieve rapid pH increase to depth in acidic soil. This report focuses on nodulation, soil pH and the N budget and strategies to ensure early crop vigour, effective nodulation and N_2 fixation, which are key to maximising the productivity and benefits of pulses in acidic soils. The findings are likely to be relevant to all pulses grown on acidic soils, across all rainfall zones.

Activities

A uniform, one hectare area was selected in each crop. In 2015 soils were sampled at standard depths of 0-10 cm and 10-20 cm, with pH measured using the calcium chloride method (pH_{Ca}). Field pH kits detected subsurface acidity at a number of sites, so in 2016 and 2017 soil cores were collected and divided into increments of 2.5 cm to a depth of 10 cm, and 5 cm increments from 10-20 cm to check for variation in soil pH in the 0-20 cm layer and for the presence of acidic subsurface layers at 5-20 cm.

Crop plants were collected from the sampling area three to four months after emergence and scored for effectiveness of nodulation (i.e. nodules formed and actively fixing N) using the Columbia protocol (Anon 1991). Scores were allocated for (1) plant growth and vigour, (2) nodule number, (3) nodule position, (4) nodule colour, and (5) nodule appearance; with all parameters of equal weighting and '25' the maximum possible total score.

Above-ground plant samples were collected by late October from the designated areas to coincide with peak biomass production and N accumulation. Using the 15N natural abundance technique, the amount of N accumulated in the shoots of the faba bean 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. The amount of legume N_2 fixed was then calculated as a percentage of the total N accumulated by the legumes (%Ndfa). This %Ndfa value is a measure of the dependence of the legume on fixed N_2. Values greater than 65% are considered high:

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

Note: Two sets of soil and plant samples were collected from the Wickliffe and Willaura crops in 2017; one designated a 'Good' area and another nearby 'Poor' area of less vigorous growth.

Results & Discussion

Sodosol is the dominant soil type at the regional sites we will discuss here. These soils have sandy to silty loam surface layers (topsoil) ranging in depth from 15 to 30 cm. The topsoils of Sodosols have low water holding capacity and can be severely acidic (pH_{Ca} <4.5). The topsoils overlay 'sodic' subsoils, which are dispersive (sodium levels from 6 to > 14%) and impermeable, which can result in perched water tables, periodic waterlogging and shallow root development. Crop variability is common, with crops growing on areas with shallow topsoil very susceptible to waterlogging (Fig. 1).

Figure 1: The faba bean crop at Kybybolite, monitored in 2016 grew in a Grey Sodosol. The 'gilgai' areas were inundated by water during the exceptionally wet July to September period.

Site and crop details for each of the 16 faba bean sites are summarised in Table 1, including soil pH and nodulation, estimates of N_2 fixation and the net addition of N to the soil pool. The crops were at Frances (2015, 2016, 2017), Kybybolite (2015, 2016), Narrapumelap (2015, 2016), Wickliffe (2015, 2016, 'Good' and 'Poor' sites in 2017) and Willaura (2015, 2016, 'Good' and 'Poor' sites in 2017).

Soil pH in the 0-20 cm layers between sites is variable, as is management to ameliorate acidity (i.e. lime rates, liming history and incorporation). At most sites lime was immediately before sowing, with the only incorporation being via the sowing operation. Only one site (Kybybolite 2015) had no lime history. In contrast the Kybybolite 2016 site received 4 t/ha of lime, incorporated to a depth of approximately 15-20 cm, prior to sowing faba bean, to eliminate subsurface acidity.

The N balance includes the amount of N added to the soil N pool by the pulse crop, which is calculated by subtracting the amount of N removed in the harvested grain, from the N_2 fixed and accumulated in the shoots. Variability in nodulation and N balance values, between seasons and sites, reveal opportunities for growers to improve productivity by minimising the risk of poor nodulation and low N_2 fixation.

Table 1. Site and crop details, the estimated amount of shoot N fixed and N added to the soil N pool by faba bean at commercial sites in SW Victoria and Frances, SA.

Location/Year		Soil pH		Sowing date	Nodulation score (max of 25)	Crop shoot biomass (t DM/ha)	%Ndfa	Shoot N fixed – kg N/t DM	Est. grain yield# (t/ha)	N balance (kg N/ha)		
		0-10 cm	10-20 cm							N_2 fixed	N removed in grain	N added to soil pool
Frances 2015 (F15)		5.2	5.0	22 May	21	3.3	43	13	1.0	45	37	8
Frances 2016 (F16)*		7.4	7.3	NA	16	9.1	73	18	3.0	161	101	60
Frances 2017 (F17)		5.6	5.6	NA	24	2.7	68	25	0.8	64	30	34
Kybybolite 2015 (Ky15)*		4.5	4.7	3 May	15	4.7	35	9	1.5	46	53	-7
Kybybolite 2016 (Ky16)*		6.1	5.3	10 May	14	3.3	69	19	1.0	62	36	26
Narrapumelap 2015 (Na15)		6.5	5.5	15 May	20	4.0	72	19	1.2	76	45	31
Narrapumelap 2016 (Na16)		5.4	4.3	28 April	23	5.5	85	18	1.6	99	61	38
Wickliffe 2015 (Wk15)*		5.8	5.9	14 May	15	4.9	57	16	1.5	76	54	22
Wickliffe 2016 (WK16)		5.2	5.0	12 May	21	10.8	83	18	3.2	194	120	74
Wickliffe 2017	Good area (WkG17)*	5.0	4.9	14 May	18	13.9	87	26	4.2	366	154	212
	Poor area (WkP17)*	4.7	5.9		8	10.7	73	23	3.2	247	119	128
Willaura 1 2015 (Wi115)		5.8	5.4	28 April	23	6.2	74	15	1.9	91	68	23
Willaura 2 2015 (Wi215)		5.3	4.8	28 April	24	6.5	65	17	1.9	112	72	40
Willaura 2016 (Wi16)		6.0	4.9	29 April	23	16.0	78	15	4.8	243	178	65
Willaura 2017	Good area (WiG17)	5.2	5.1	10 May	23	12.3	99	23	3.7	287	137	150
	Poor area (WiP17)	4.5	4.6		21	8.3	93	25	2.5	205	92	113

Grain yield was estimated from peak dry matter cuts using an estimated harvest index of 0.30 for faba bean. * Unsatisfactory nodulation scores are explained.

Effective nodulation is essential for productive pulses

Nodules are formed when sufficient rhizobia are in contact with and infect the emerging root. N_2 fixation only occurs when conditions are suitable for growth and function of both the host plant and the rhizobia. **The risk of poor nodulation and low N_2 fixation increases with adverse conditions and/or management practice that restrict the growth and activity of either plant or rhizobia.**

The relationship between soil pH and nodulation scores for the 45 acid-sensitive pulse crops surveyed in this project (faba bean, lentil and chickpea) is shown in Figure 2. In general the crops fell into two categories: (i) vigorous, well nodulated crops; and (ii) those with a nodulation score below 18 (i.e. unsatisfactory nodulation), which included extremely variable and stunted crops that showed symptoms of N deficiency within 3 months of emergence. The SA and SW Vic crops are marked as red circles to indicate satisfactory nodulation or black crosses for unsatisfactory nodulation (nodulation scores < 18).

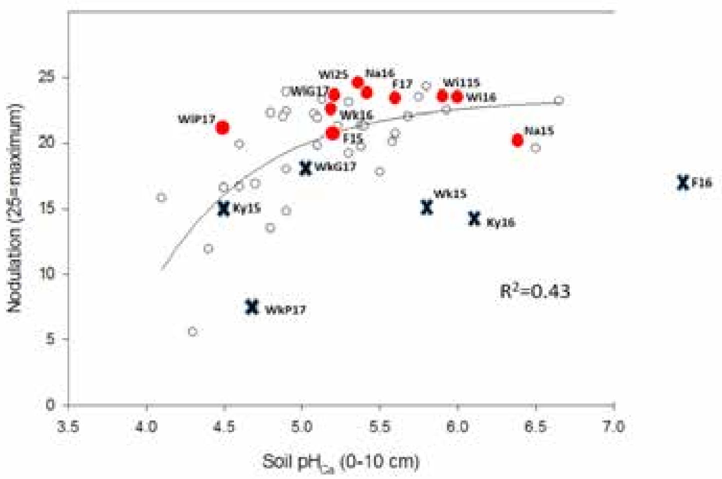

Figure 2: The relationship between soil pH_{Ca} in the surface 0-10 cm sample and nodulation in pulse crops (R^2=0.43) in SE Australia. The red dots show regional sites with satisfactory nodulation scores and crosses show sites with poor scores. The abbreviations F, Ky, Na, Wk and Wi represent Frances and Kybybolite (SA) and Narrapumelap, Wickliffe and Willaura (Vic) sites, with numbers indicating the crop year, as shown in Table 1.

Analysis of the nodulation scores and pH_{Ca} of 0–10 cm soil samples from all sites showed a correlation (R^2=0.43) where low pH was associated with poor nodulation and higher pH indicative of better nodulation. This is as expected, because the survival of the strains of rhizobia specific for acid-sensitive pulse species is compromised at pH below 5.0 (Drew et al 2012). However, at a number of sites with soil pH_{Ca} < 5.0 nodulation was 'satisfactory' (i.e. score >18), but Figure 2 indicates that the risk of poor nodulation increased as pH declined.

Satisfactory nodulation at sites with low pH (e.g. a nodulation score of 21 at **WiP17** with 0-10 cm pH_{Ca} 4.5) coincided with favourable conditions during sowing and seedling establishment, which allowed effective nodule formation and function. We concluded that plants may nodulate effectively in moderate to severely acidic sites provided the establishing crop is free of additional stresses, such as waterlogged conditions, cold temperatures, plant disease and herbicide injury. Such crops were generally sown into free-draining soils on time!

Clearly, not all of the 16 sites shown in Figure 2 sit close to the line (the R^2 relationship), which tells us that while unsatisfactory nodulation at the Ky15 and WkP17 sites was likely caused by low pH_{Ca} (4.5 and 4.7, respectively), other factors limited nodulation at the higher pH sites (Wk15, Ky16 and F16) with pH_{Ca} of 5.8, 6.1 and 7.4, respectively. Further investigation of these outliers allowed us to pinpoint stresses, besides low pH, that can disrupt nodule formation and nodule function.

Forms of inoculant used in the 45 crops surveyed across the entire project included peat slurry, freeze-dried and granular. There was no evidence that form of inoculant used in the commercial crops affected the nodulation score. However, poor nodulation (15) at **Wk15** was due to insufficient rhizobia in contact with the seed, put down to bridging and poor distribution of granular inoculant during the sowing operation.

Poor nodulation at the **Ky15** (15) and **Ky16** (14) occurred because zinc oxide was mixed with the rhizobia peat slurry. This demonstrates the risk of rhizobial death when the bacteria are in contact with toxic products. Trace elements such as zinc and copper, acidic chemicals and many pesticides are extremely toxic to rhizobia. Check chemical and pesticide labels for compatibility and strictly adhere to label recommendations. If in doubt, do not mix any product in the rhizobia slurry.

The low nodulation score of 16 at **F16** (Frances 2016) was surprising. It was the only alkaline site monitored (pHCa 7.4 at 0-10 cm), so pH wasn't the issue, but the site was very wet following above average rainfall from July 2016. Note that any stresses, such as waterlogging, that reduce plant vigour, will slow nodule development and function. Although many F16 plants had a satisfactory number of nodules, they were small and pale inside. Waterlogged conditions during the seedling stage of the 2017 Wickliffe crop was also the likely reason for the poor nodulation scores at **WkG17** (18) and **WkP17** (8).

Nodulation scores for **F16** (16), **WkG17** (18) and **WkP17** (8) were assessed during cold, wet winter conditions that restricted growth of plants and rhizobia. Nodules were concentrated in the shallow surface soil, which suggests that adverse conditions at depths below about 5 cm limited nodule development on deeper roots: e.g. waterlogging at F16 and a combination of waterlogging and subsurface acidity at WkG17 and WkP17. However, the relatively high %Ndfa (the proportion of legume N coming from the atmosphere) for F16, WkG17 and WkP17 (73, 87 and 73%, respectively) indicates that nodule function and plant growth (and nodule activity) improved as soils dried and temperatures increased. This was confirmed by October visits to the sites, when large, active, dark-pink nodules, were concentrated in the better drained shallow surface soil (Figure 3). The dark-pink colour indicated that the rhizobia were actively fixing nitrogen.

This reflects our experiences at other sites; faba bean can be reasonably productive in acidic soils, provided the shallow soil surface layers support healthy root and nodule development and seasonal conditions remain mild during spring and the plant doesn't suffer moisture stress during the critical flowering and pod-fill periods.

Figure 3: Despite waterlogged conditions and pH stratification limiting nodule formation to the shallow surface layers at the Poor 2017 Wickliffe site (WkP17), the crop yielded 3.2 t/ha.

Nodulation, pH stratification and subsurface acidity

Before sowing acid-sensitive crops collect samples from intervals of 5 cm to check for the presence of acidic layers at 0-20 cm,. Soil pH measured from samples collected from the traditional sampling depths of 0-10 cm will not detect pH stratification and acidic subsurface layers at 5-15cm. For example the pH_{Ca} tests of the bulked 0-10cm soil samples from Na 16, WkG17 or WiG17 sites would have returned results of 5.2, 5.0, and 5.2, respectively, giving the false impression that pH was in the satisfactory range for faba bean (Table 2). A garden soil test kit can provide a quick and cheap indicator of acidic layers.

Table 2. Soil pH_{Ca} profiles from 2016-17 sites show the importance of sampling at fine increments to check for pH stratification within the 0-20 cm layers. The asterisk against some nodulation scores indicates that factors besides low pH may have contributed to unsatisfactory nodulation at these sites.

	Sites with detailed sampling in SA and SW Victoria							
Soil depth (cm)	Frances 2016 (F16)	Kybybolite 2016 (K16)	Wickliffe 2016 (Wk16)	Narrapumelap 2016 (Na16)	Wickliffe G2017 (WkG17)	Wickliffe P2017 (WkP17)	Willaura G2017 (WiG17)	Willaura P2017 (WiP17)
0-2.5	7.3	6.5	5.5	6.3	5.2	4.6	5.7	4.9
2.5-5.0	7.4	5.9	5.2	5.3	5.1	4.6	5. 5	4.4
5.0-7.5	7.5	5.6	5.2	4.7	5.0	4.7	4.9	4.3
7.5-10	7.4	6.2	5.0	4.4	4.8	4.9	4.7	4.3
10-15	7.3	5.3	5.3	4.3	4. 8	5.4	4.8	4.3
15-20	7.2	5.3	4.7	4.4	4.9	6.3	5.4	4.9
Nodulation score	16*	14*	21	23	18*	8*	23	23

Observations from pulse crops surveyed at the 45 project sites indicates that production and N2 fixation of acid-sensitive pulses declines as pH_{Ca} falls. We noted rooting density and depth, root hair development and nodule formation was visibly reduced at soil pH_{Ca} below approximately 4.8.

Detailed soil samples collected from eight of the SA and SW Victorian sites (Table 2), identified moderate to severe acidity may have reduced pulse production potential within the subsurface layers (5-20 cm) at all except the Frances 2016 and Kybybolite 2016 sites.

Note the contrasting pH profiles for the two sites from the same 2017 crops at Wickliffe and Willaura sites, which suggest uneven lime application rates or areas of lime misses. The elevated pH in the 0-7.5 cm layers of the WkG17 and WiG17 indicates lime has increased pH in the surface soil layers at these sites, compared with the more acidic sites in the same paddock, WkP17 and WiP17.

Nitrogen fixation and the nitrogen contribution to the next crop

Variable yield and the unpredictable N contribution of pulse crops was raised as concerns by industry during the project team's 2015 consultation meetings with growers and advisors. The 'rule-of-thumb' figure widely used to estimate the amount of N_2 fixed by legumes is 20 - 25 kg of shoot N per tonne of above-ground (shoot) dry matter (DM). However, previous studies (e.g Peoples et al 2015) report large variation in the amounts of N_2 fixed per tonne of DM produced by crop and pasture legumes. In our study the amount of N_2 fixed by faba bean ranged from 13 - 25 kg N/t of shoot DM, with the total amount fixed per hectare ranging from 45 - 366 kg N (Table 1).

Understanding the reasons for the variability in the amount of N_2 fixed by the commercial crops surveyed creates opportunities to improve efficiencies of N_2 fixation and the yield of pulses growing in acidic soils by adjusting current practices.

The proportion of legume N fixed from the atmosphere (%Ndfa) for each site is shown in Table 1. This measure is an indicator of the effectiveness of the nodulation process and the vigour of the plant. The %Ndfa figures ranged from 35% for the poorly nodulated plants at Kybybolite (K15) site to 99% in the Good area of the 2017 Willaura crop (WiG17).

In 'normal' seasons of adequate moisture and warm temperatures, spring should be the time of maximum shoot growth and N_2 fixation rates. The relatively dry conditions during spring of 2015 across all sites severely limited both. So it is not surprising that the %Ndfa measured in 2015 were the lowest for each of the locations and resulted in the lowest estimated net addition of N to the soil pool. In contrast the mild, wet conditions during spring of 2016 (and 2017 in SW Victoria) were ideal for vigorous plant growth, dry matter accumulation and N2 fixation rates.

The net addition of N to the soil pool by the pulse crops ranged from a net loss of -7 kg N/ha at the K15 site to an additional 212 kg N/ha at the WiG17 site. The link between between N accumulation in the shoot (N fixed), N exported in the grain and N remaining in the soil pool (N addition) is shown in Figures 4 (the SA sites) and Figures 5 (the SW Vic sites).

We can only draw broad conclusions from the results because of the high variability in soil condition, sowing times, management practices and seasonal conditions between sites. In general, the higher yielding sites fixed the most shoot N and added most to the soil N pool, but there are exceptions to this. For example the highest yielding site (estimated 4.8 t/ha grain at Wi16) had one of the lowest values for N fixed per tonne of DM (15kg N/t DM) with 78 %Ndfa, and contributed an estimated 65 kg N /ha to the soil N pool. The greatest soil N contribution (212 kg N/ha) was at the WkG17 site, which also had the highest amount of shoot N fixed (26 kg N/t DM) and a high 87%Ndfa.

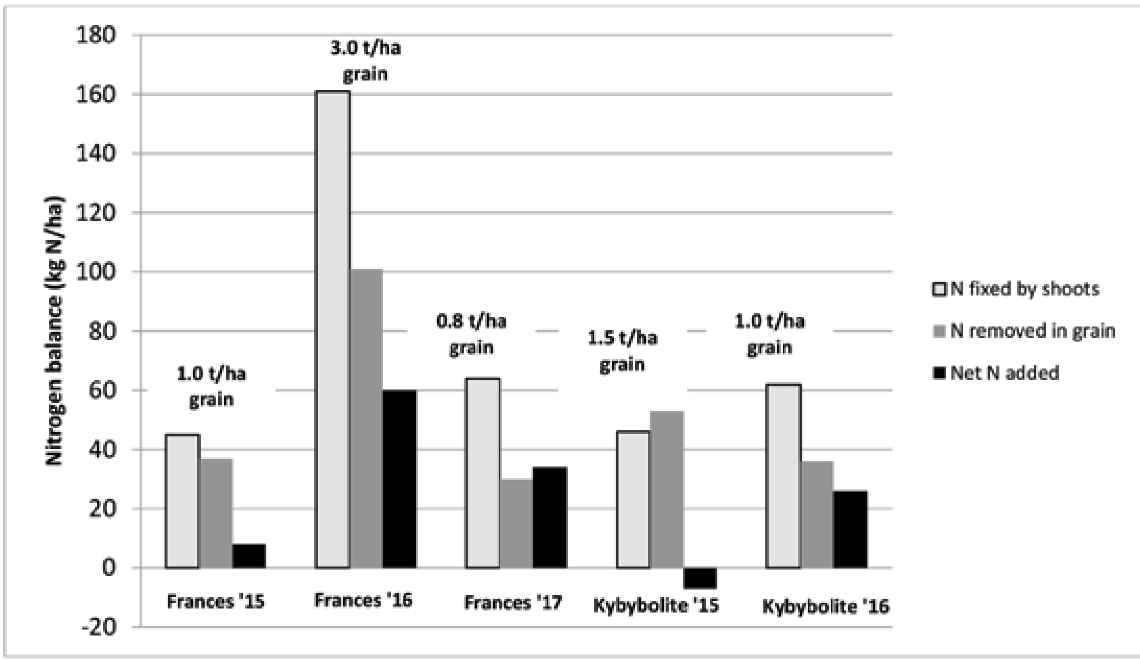

Figure 4: The N balance (kg N/ha) for 2015 to 2017 SA sites calculated from measurements of N fixed by shoots, the estimated N removed in harvested grain and the net addition of N to the soil pool. Estimated grain yield is above the columns for each site.

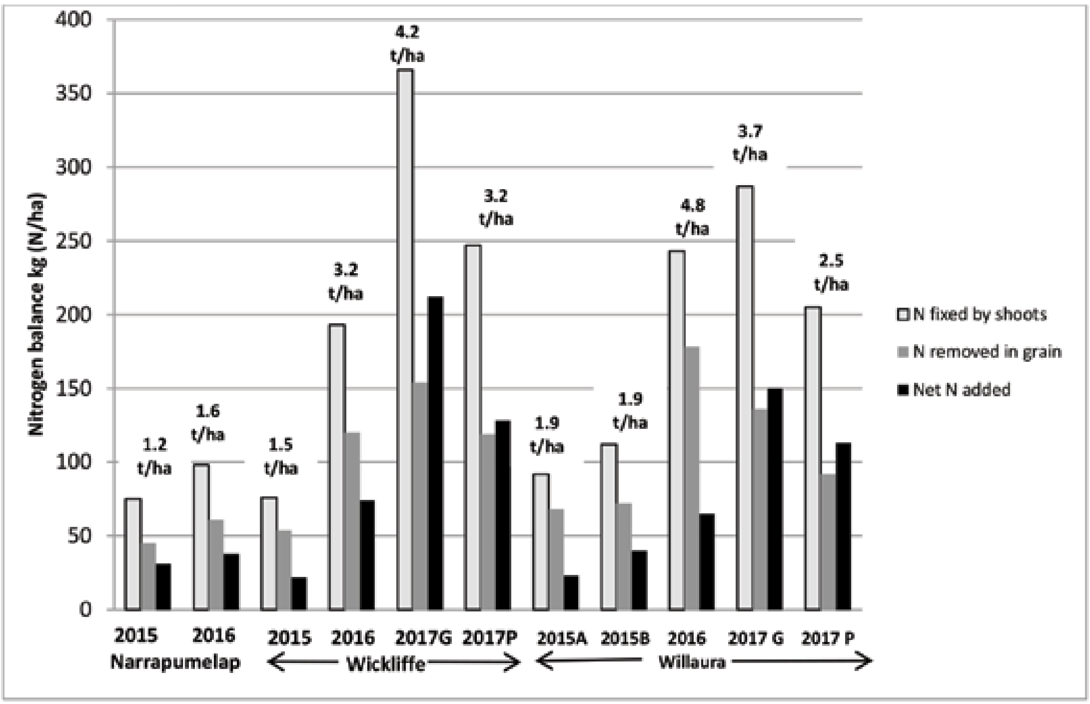

Figure 5: The N balance (kg N/ha) for 2015 to 2017 SW Victoria sites calculated from measurements of N fixed by shoots, the estimated N removed in harvested grain and the net addition of N to the soil pool. Estimated grain yield is above the columns for each site.

Conclusions

Our investigations indicate that soil pH influences root development, nodule formation and early vigour of pulses, which in turn set the yield and N_2 fixation potential of acid-sensitive pulses. We observed that the lower the pH in the subsurface layers, the greater the risk of poor nodulation, the less vigorous the seedlings and the greater the susceptibility of the acid-sensitive plants to other stresses.

The key to achieving consistent and profitable productivity from pulses growing in acidic soils is effective nodulation, seedling vigour and minimising stresses in order to maximise biomass accumulation and to minimise any stresses that could reduce early plant and rhizobial activity. Fundamental to this is (i) forward planning; (ii) paddock selection based on an understanding of soil types, including pH of the soil profile; and (iii) attention to crop agronomy. Follow the checklist below when choosing paddocks for acid-sensitive pulses:

1. Start planning at least 2 years before sowing acid-sensitive pulses.
2. Check for the presence of acidic layers at 0-20 cm.
3. If in doubt, have samples analysed by an accredited laboratory, ideally collected at 5 cm intervals to a depth of 20 cm.
4. Avoid sowing acid-sensitive pulses in soils prone to waterlogging, i.e. with a shallow topsoil and impermeable subsoil.
5. Avoid paddocks with heavy infestations of broadleaf weeds or herbicide resistant grass weeds that cannot be effectively controlled by a combination of pre-sowing control and in-crop herbicides.
6. Check herbicide use in the previous 12 – 24 months and ensure maximum plant-back periods are satisfied, with particular attention to Group B, chlorpyralid and triazine herbicides:

   - avoid sowing legumes sensitive to sulfonylurea (SU) in paddocks on which SU herbicides have been used in the last 12 – 24 months. Check herbicide labels – e.g. when surface (0-5 cm) soil pH_{Ca} > 5.8, plant-back interval can be up to 22 months.

   - chlorpyralid (Lontrel™) persists in residue of treated crops and may damage legume species. Check herbicide labels for plant-back intervals.

   - high herbicide rates on the light textured soils typical of the region may cause phytotoxicity, (e.g. root pruning and reduced nodulation). Check herbicide rates!
7. Minimise disease risk in pulse crops by following cropping interval and crop separation guidelines.
8. Sow on time, early in the recommended sowing window, to allow plants and nodules to establish before cold temperatures slow growth and rhizobial activity.

These points are covered in more detail in a new guide, 'Legumes in acidic soils' in the Further reading list. It was produced as part of this project and is available online.

Further Reading

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