21. Improving the performances of pulses on acidic soils of the high rainfall zone of south eastern Australia

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KEY MESSAGES

- Most legumes favour pHCa > 5.0 to a depth of at least 20 cm; acidic layers below 5 cm adversely affect root growth, nodulation, plant vigour and N2 fixation potential of acid-sensitive pulses.
- Ineffective incorporation of lime under minimum tillage systems confines the lime effect to the shallow surface layers (0-5 cm).
- An 'acid throttle' located between 5 to 20 cm in the soil profile is not detected using soil samples collected at standard depths of 0-10 cm and 10-20 cm, finer sampling at 5 cm intervals is recommended to detect acidic layers.
- Apply and incorporate adequate rates of fine grade, high quality lime at least 12 months before sowing acid-sensitive species to allow time for the lime to react and increase pH to the depth of incorporation.

Background

The experiences of growers and advisors indicate that faba bean is the pulse crop best adapted to soils prone to waterlogging. It is the pulse of choice in the acidic soil regions of the high rainfall zones of SA and SW VIC, and Gippsland. However, while faba bean are successfully grown on slightly acidic soils (pHCa >5.0 - 6.0), widespread adoption of faba bean and other acid-sensitive pulses (e.g. lentil and chickpea in NE Victoria and southern NSW) is limited by inconsistency of yield and perceived high production risk.

This paper focuses on the preliminary findings of a NSW Department of Primary Industries project, supported by GRDC, aimed at identifying factors limiting the production and nitrogen fixation of pulse crops grown on acidic soils in the high rainfall zone (HRZ) grain production regions of south eastern Australia with a long-term average annual rainfall above 500 mm.

Our findings are likely to be relevant to pulses grown on acidic soils across all rainfall zones. Furthermore, the severity of the acidity detected below 5 cm depth at a number of sites is sufficient to be affecting the productivity of the main crop and pasture species, including cereals and canola.

Activities

During the winter cropping seasons from 2015 to 2017, a total of 39 commercial pulse crops were monitored in NSW, Victoria, SA and Tasmania (Figure 1). Sodosols were the dominant soil type at the sites monitored in SW Vic and in the vicinity of Frances in SA. The distinctive features of these soils are sandy to silty loam surface layers to depths ranging from 15 to 30 cm (the A horizon), overlying 'sodic' subsoils (B horizon). The subsoils are dispersive (sodium levels from 6 to > 14%) and impermeable, which can result in perched water tables and transient waterlogging.

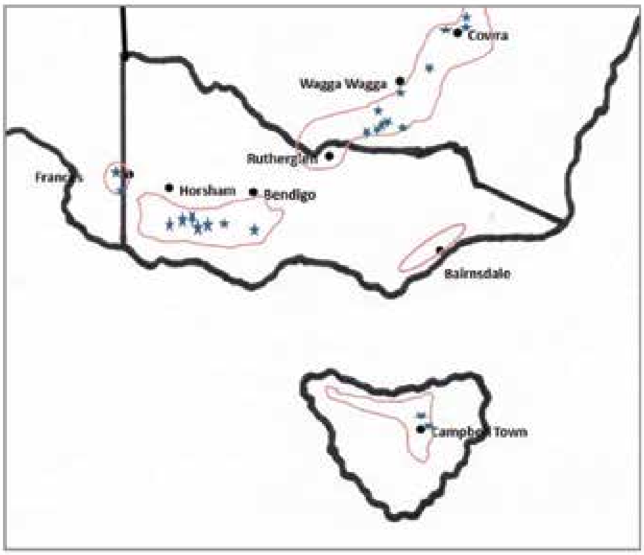

Figure 1. The acidic soil region of the high rainfall cropping zone of south eastern Australia showing the location of paddocks monitored during the 2015 to 2017 growing seasons.

This report will concentrate on the results and observations from the 24 faba bean crops monitored at the SA and SW Victoria sites within the project area from 2015 to 2017. A uniform, one hectare area of crop was selected at each site. Soils were sampled at standard depths of 0-10 cm and 10-20 cm, with pH measured using the calcium chloride method (pHCa) through Nutrient Advantage Laboratories.

Crop plants were assessed two to three months post-emergence for effectiveness of nodulation. Plants with intact root systems were collected at random from the designated areas and scored for nodulation 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.

Late in the 2015 growing season (October 2015) root growth of crops that recorded poor nodulation scores were inspected and soil pH assessed using a Manutec® Soil pH Kit; in 2016 and 2017 in situ and soil cores were collected from all monitored sites and divided into increments of 2.5 cm to a depth of 10 cm, and 5 cm increments from 10-20 cm. Soil pHCa was measured in the NSW DPI Wagga Wagga laboratory. The soil pH profiles for 2015 2016 acidic sites with a pHCa < 5.5 in the 0-10 cm surface layer are reported below.

An experimental site was established near Wickliffe, Victoria, in April 2016 to compare the effect of 3 rates of lime and the role of thorough incorporation on improving the rate of pH change in the surface 0-10 cm. Fine (F70 grade) ag-lime, with a neutralising value (>95%) was applied at rates of 0, 1, 2 and 4t/ha, either incorporated into the top 10 cm of the profile (using a rotary hoe), or not incorporated and left on the soil surface. Faba bean were sown on the site using knife points. Soil samples were collected from this site at 2.5 cm sampling intervals, in November, 2016.

Results & Discussion

Across contrasting growing seasons from 2015 to 2017, the negative impact of low pH on the nodulation and early vigour of faba bean crops was consistent, and undetected severely acidic layers (pHCa <4.5) in the surface soil (0-20 cm) appears to be a primary factor limiting the production potential of faba bean on the acidic soils of the region. This was apparent in the exceptionally dry conditions in 2015 (45 – 65% growing season rainfall in SW Vic and SA) and again in 2017, when the additional stresses of waterlogging and cold temperatures from June until September appeared to reduce nodule function.

Soil acidity and nodulation

The environment to which both the rhizobia and host plant are exposed influences the success of the complex nodulation process. The optimal pHCa range for Rhizobium spp. used for faba bean and lentil (Group F) is > 6.0, but the nodulation process is severely disrupted at pHCa below 5.0.

Consultation with growers indicates that while the inoculation process and use of the appropriate rhizobia strain are well understood, the management required to avoid stresses that compromise root development and rhizobial function during the nodulation process is not. Stresses such as soil acidity, residual herbicides and toxic minerals (e.g. zinc) mixed with the rhizobia during the inoculation process appear to reduce the early vigour and production potential of faba bean crops monitored in this study.

The negative effect of low pH on nodulation of faba bean crops included in this study is shown in Figure 2. Analysis of the nodulation scores for faba bean crops and pH of 0–10 cm soil samples showed a correlation ($R2=0.42$) where low pH was associated with poor nodulation, while pHCa approaching 5.0 resulted in satisfactory nodulation. When nodulation score was related to crop appearance, the monitored crops fell into two distinct categories: (i) vigorous, well nodulated crops; and (ii) those with an unsatisfactory nodulation score (< 18), which included extremely variable crops that showed symptoms of nitrogen deficiency within two to three months of emergence (circled in Figure 2). These included sites at Lismore (VIC) and Kybybolite (SA) sites, which recorded nodulation scores of 17 and 15, respectively.

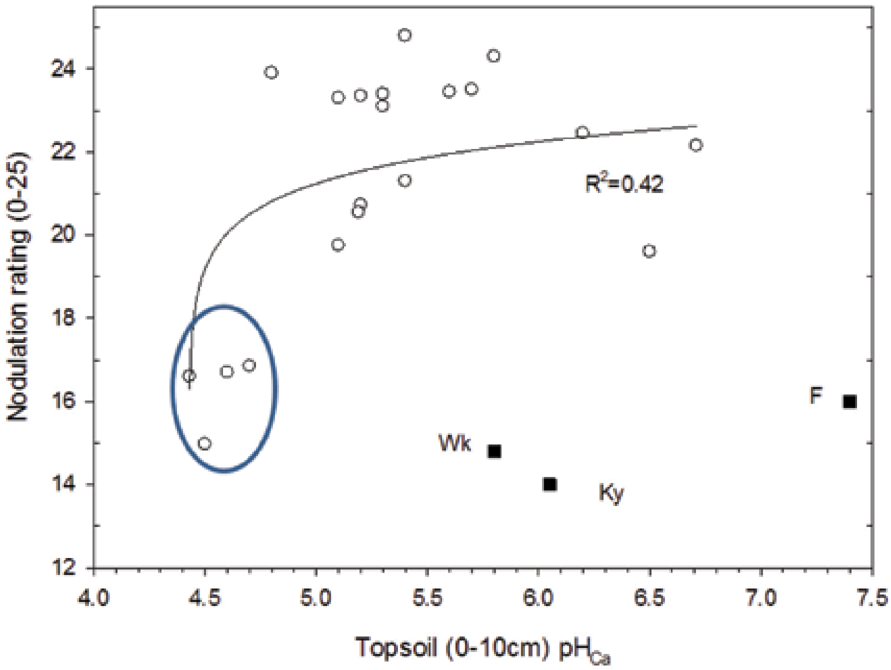

Figure 2. The relationship between soil pHCa and nodulation for a range of commercial pulse crops across south east Australian high rainfall zone acid soils (R2=0.42). The abbreviations Ky, F and Wk represent 'outliers', the crops at Kybybolite and Frances (SA) and Wickliffe (Vic), which are not included in the correlation analysis.

Note the poor nodulation scores for the 'outliers' indicated in Figure 2, which all had low nodulation scores despite having relatively high 0-10 cm pH. Poor distribution of granular inoculant at Wickliffe resulted in insufficient rhizobia in contact with emerging seedlings at Wickliffe (Wk), zinc mixed with inoculant during the inoculation process reduced rhizobia survival at Kybybolite (Ky) and severely waterlogged conditions soon after sowing affected the nodulation process at Frances (F).

Figure 3. Faba bean failed to nodulate when zinc was mixed with the rhizobia inoculant during the inoculation process – as can be seen in the area of crop on the right. (Photo credit Roy Hamilton).

Soil pH stratification

The pH test results from soil samples collected from the standard sampling depth of 0-10 cm, which is traditionally used by growers and advisors to guide decisions on acid soil management, did not detect the acidic layers within 5-10 cm. The soil pH profiles averaged across 11 sites are shown in Figure 3. These sites had either severely acidic (pHCa < 4.5) or moderately acidic layers (pHCa 4.5 – 5.0). Ten of these sites had a recent history of liming.

At sites (3) where the lime was applied in the year of sowing and approximately 6 months prior to sampling, it remained concentrated in the shallow surface layers. At these sites the pH dropped sharply below 5 cm: 1.6 units from pHCa 6.3 at 0-2.5 cm to pHCa 4.4 at 5.0-7.5 cm. The intense pH stratification identified by testing finer 2.5 cm layers indicated that under the no-till systems used by the majority of participating growers, the lime had limited effect on raising pH in the layers below 5 cm. Lime moves very slowly below the depth it is incorporated and clearly, under no-till systems in the commercial crops, lime topdressing with no incorporation is ineffective in neutralising acidity below about 5 cm depth in the short term.

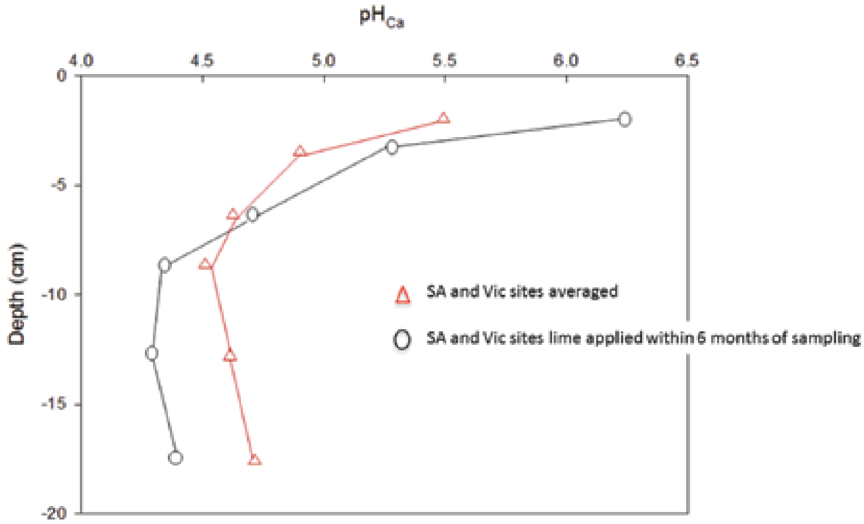

Figure 4. Ineffective lime incorporation under minimum tillage systems at 11 acidic sites results in elevated pH in the shallow surface layer (0-5 cm). The lime has limited effect in raising pH below 5 cm.

Effect of lime rate and incorporation on pH change

An experimental site at Wickliffe, established to measure the impact of lime rate and incorporation method on pH, had a strong history of lime application. The grower applied 2.5 t/ha of locally sourced lime in 'the 1990s, 2005 and 2014. The lime was applied to the surface on each occasion and only incorporated by the sowing operation. As was the case with the commercial sites shown in Figure 3, the pH of the surface 5 cm at the experimental site (Figure 4) was elevated. The pH dropped approximately 1 unit: pHCa 6.0 at 0-2.5 cm to pHCa 5.1 at 5.0-7.5 cm.

Without having historic pH values for 0-10 cm layers, it is impossible to gauge the impact that the strong lime history at this site has had on subsurface pH, but with a pH of > 5.5 in the top 5 cm for the 'Nil lime rate', it is likely that there has been some movement of the lime effect into the 5-10 cm layer, although the pH of the 7.5-10 cm layer remains moderately acidic (4.7).

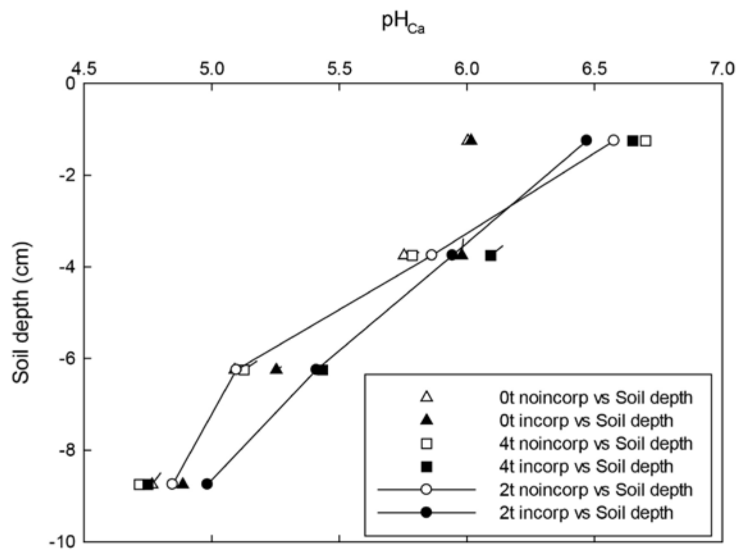

Figure 5. Soil pHCa values in November 2016, 7 months following lime application, measured at 2.5 cm intervals to a depth of 10 cm, show the impact of 3 lime rates (0, 2 and 4 t/ha of fine grade lime) and the effect of incorporation with a rotary hoe versus surface application prior to the sowing operation (using narrow points).

Addition of lime in 2016 resulted in an elevated pH of the surface 0-2.5 cm, in both the incorporated and no incorporation treatments. The pH results from samples collected seven months after lime application do not reflect the potential for the applied lime to increase in pH. Lime reacts slowly and even 12 months following thorough incorporation only 60-70% of incorporated lime will have 'reacted' to cause an increase in measured pH (B Scott, pers. comm.).

The 4 t/ha lime rate was the only treatment at Wickliffe that produced a significant change in subsurface pH, and only at the 2.5 – 5.0 cm layer, with an increase of 0.57 units above the Nil lime treatment. The final pH test results for the site are not yet available.

The slow rate of pH change shown in this experiment highlights the importance of a long lead time when planning to sow acid sensitive species. Timing of lime application must take into account low solubility of lime and slow movement of the lime effect into layers below the depth of incorporation, and should occur at least 12 months prior to sowing sensitive species. A longer lead time of at least 24 months is necessary in lower rainfall areas and when lime is applied to the surface and only incorporated by the sowing operation.

Conclusions

Effective nodulation underpins productive and profitable pulse crops. When detailed soil pH data were aligned to root growth and nodulation of pulse crops, the presence of previously undetected, but severely acidic layers, was likely to be a major factor responsible for inconsistent 'performance' of acid-sensitive pulses on slightly (pHCa >5.0) and moderately acidic soils (pHCa 4.6-5.0) at 11 of the 24 sites in SA and Victoria included in this study.

At a sowing depth of about 7cm, the germinating faba bean seeds, rhizobia and young seedlings would experience more severe acidity than indicated by the standard soil tests. The seedling's early root growth would be in the most acidic soil in the profile. Optimal nodulation requires pH conditions favourable to both the rhizobia and host plant. The impact of acidic layers on root hair development and nodulation was apparent in all crops that demonstrated poor nodulation.

Faba bean is proving to be 'the canary in the coal mine' for detecting acidic layers. The dramatic clinical symptoms expressed by faba bean plants exposed to acidic layers has helped highlight the extent and severity of pH stratification, even in soils with a long history of lime application.

Management of pulses sown in acidic soils must focus on promoting the nodulation process and minimising or avoiding environmental stresses. The results from this project, reinforced by grower experience, indicate that well nodulated, vigorous pulse crops have the ability to withstand multiple stresses, including infection by root diseases and transient waterlogging. Our experiences indicate that timely sowing, early in the recommended sowing window, allows plants and nodules to establish before cold temperatures slow growth and rhizobial function.

The intensity of soil pH stratification identified by testing finer layers demonstrates that lime was concentrated in the shallow surface layers (0-5 cm) under the no-till systems adopted by the majority of participating growers. This study indicates that current acidic soil management and liming programs are ineffective in neutralising subsurface acidity and lime rates are often insufficient to counteract acidification below the shallow surface layers.

Soil sampling methods

- Soil samples collected at standard depths of 0-10 cm and 10-20 cm will not detect pH stratification. Occasional finer sampling at 5 cm intervals is recommended to verify the presence of an acid throttle.
- Periodic testing at 5 cm intervals (e.g. every 3 to 5 years) will provide valuable data that can be used to objectively assess the effectiveness of acidic soil management strategies and to guide the rate and frequency of lime applications.

Lime rates and application methods

- The current standard industry practice of spreading lime with no incorporation and sowing with knife point press wheels or disc seeders confines the lime effect to the shallow surface layers (0-5 cm).
- The severe acidity identified in the 5-20 cm layers at many sites indicates that current lime rates are too low to raise pH in the top 10 cm and insufficient to prevent acidification further down the profile.
- A rapid solution to severely acidic layers in the surface soil (0-10 cm) requires an aggressive approach that involves appropriate lime rates and effective incorporation with strategic cultivation to a depth 10 cm.
- Delay sowing acid-sensitive species for at least 12 months after lime incorporation, to allow time for lime to increase pH.
- For erosion-prone soils where cultivation is not appropriate, it may be necessary to delay sowing acid-sensitive species until the lime effect moves down the profile. The rate the lime effect moves down the profile depends on lime quality and rate, soil type and rainfall.
- In the longer term, if the pHCa of the 10-20 cm layer is <5.0, liming to maintain the 0-10 cm surface layer at pHCa > 5.5 will facilitate movement of the lime effect into the acidic layers at 10-20 cm and avoid further acidification of these subsurface layers.

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