Soil and management impacts on potential legume production: results of a survey of 300 commercial paddocks in the GRDC northern region

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Key words

grain legumes, pasture legumes, acidity, phosphorus, sulphur, organic carbon, herbicides

GRDC codes

9175959
DAN1901 002 RTX

Take home message

- Soil acidity is a widespread issue across the growing regions surveyed and is likely to be impeding optimal performance of grain and pasture legumes with respect to plant growth and nitrogen fixation
- Phosphorus levels are generally above, and often well in excess of critical levels required for grain and pasture legume production but there is an uneven distribution of phosphorus availability within the soil profile
- Sulphur levels are generally adequate in cropping paddocks, but frequently inadequate in pasture paddocks which may impact legume performance
- Soil organic carbon levels vary significantly with region, and within some regions as a result of land use (crop vs pasture)
- Reallocation of input expenditure to ameliorate soil acidity and the use of strategic cultivation may assist in alleviating some soil constraints to legume production across these regions.

Background

There is increasing opportunity and options for the use of legumes in rotation systems in the mixed farming zone. Both grain and pastures legumes offer greater flexibility in rotation systems by providing a disease break and allowing the use of a different spectrum of herbicides to control weeds that impact cereals and canola thus prolonging the useful life of herbicides. In the case of pasture legumes, grazing can also be used strategically with herbicides to control weeds. Central to the use of legumes in rotations is their capacity to contribute significant quantities of biologically fixed nitrogen for use by following crops. The capacity of legumes to supply nitrogen can considerably reduce fertiliser input costs. However, harnessing nitrogen fixation capacity requires legumes and their rhizobia to achieve an effective symbiosis (that is, form effective nodules). If effectively nodulated, the quantity of nitrogen fixed is then a function of how much biomass (herbage) the plant produces. Soil factors and management strategies imposed prior to sowing legumes and in years when they are grown in the rotation can have a significant impact on their capacity to form an effective symbiosis and reach nitrogen fixation targets of 20-40 kg N/t dry matter (DM). In 2019, a survey of 300 commercial paddocks across 150 farms was undertaken across four GRDC growing northern region to quantify soil chemical characteristics and assess likely regional limitations to legume growth. Concurrently, the participating growers completed a management survey providing information on the management of each paddock over the previous five years. The management survey included collection of information on paddock use over the past five years, herbicide and fertiliser inputs, grazing management and intended future use of the paddock. Additional information collected included botanical composition and ground cover at time of sampling. In this paper, preliminary results of some soil chemical characteristics and key management findings impacting legume growth and nitrogen fixation are presented.

Methodology

Farms included in the field survey were selected using farming system groups, advisors, local land services and by drawing on previous databases held by the project team. Growers were asked to provide two paddocks for sampling, with our preference being one paddock in crop and one in pasture on each farm.

A representative area of the paddock measuring 50m x 50m was selected for sampling. A minimum of 16 cores to a depth of at least 30cm were collected from within the sampling area. The soil cores were divided into segments of 0-5, 5-10, 10-20 and 20-30cm with each depth bulked together for analysis. All chemical analyses were undertaken by Nutrient Advantage laboratories (Werribee Victoria). Analyses included pH_{Ca}, total carbon and nitrogen (LECO) and available sulphur (all depths) and available phosphorus (Colwell) and cation exchange capacity (0-5 and 5-10cm depths only). In this paper we report; pH_{Ca}, total carbon, available P and available S results and key findings of the management survey.

Results and discussion

Paddocks sampled

There was a slightly higher prevalence of cropping paddocks sampled in the central west and south west growing regions, whereas there was a higher prevalence of pasture paddocks sampled in the central east and south east growing regions (Table 1). These differences are reflective of variance in land use across the regions.

Table 1. The number of crop and pasture paddocks where soil was collected for analysis and management history collected in the central east, central west, south east and south west GRDC northern region growing regions.

	Central east	Central west	South east	South west
Crop	26	47	31	30
Pasture	62	42	40	22
Total	88	89	71	52

Soil pH_{Ca}

There were differences in soil pH_{Ca} associated with land use (crop or pasture), soil depth and between regions, but these were not always statistically significant (Figure 1). For example, in the central west growing region, the pH_{Ca} of the soil profile was greater at all depths beyond 5cm in cropping paddocks compared to pasture paddocks. However, there were no significant differences between crop and pasture paddocks in the other regions. Similarly, there were differences in soil pH_{Ca} associated with soil depth but these differences varied within and between regions. For example, the pH_{Ca} of the 5-10cm soil layer was significantly lower than the 0-5cm layer in the south east growing region, but not in any other region. The pH_{Ca} of the 5-10cm layer was significantly lower than the 10-20cm layer in the south west growing region. The pH_{Ca} of the surface 10cm of soil was significantly lower in the south east growing region compared to the central west, while both eastern regions had a lower pH_{Ca} in the 20-30cm layer than either of the western growing regions.

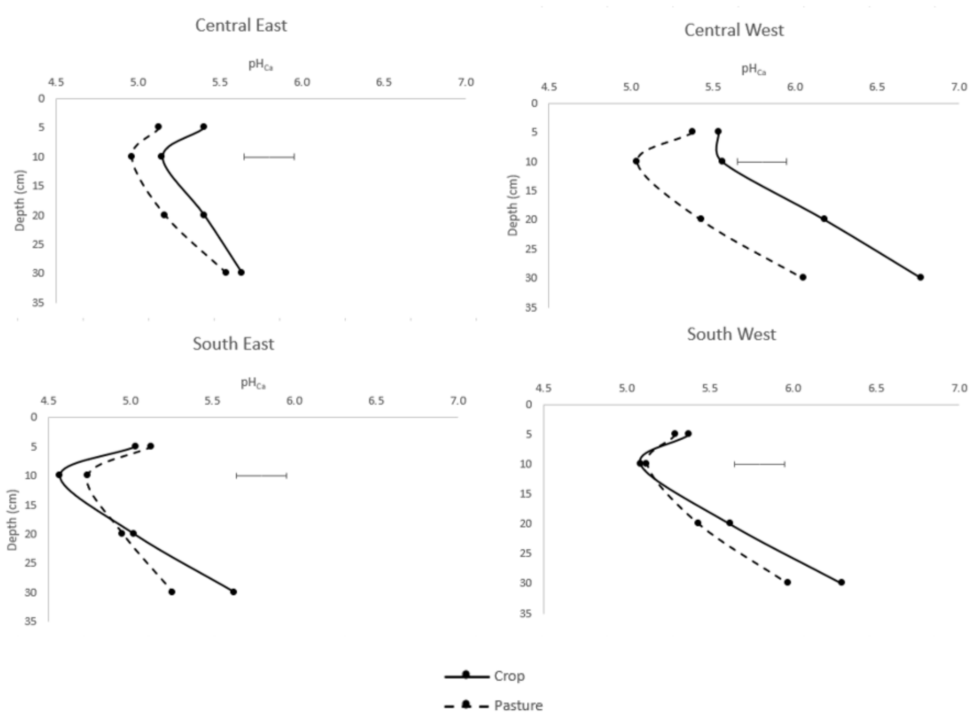

Figure 1. Soil pH_{Ca} for crop and pasture paddocks in the central east, central west, south east and south west GRDC northern growing regions for 300 paddocks sampled in 2019. LSD at P<0.05 indicated.

Implications of soil pH for legume growth

The host legume plant and its associated rhizobia have specific tolerances to soil pH. For most grain and pasture legumes, growth of the host plant will not be compromised at soil $pH_{Ca} \geq 5.0$. However, for the rhizobia associated with many of these plants, their survival and effectiveness generally begin to suffer some decline when $pH_{Ca} < 5.5$. Thus, there is a discrepancy in tolerance between the host plant and its rhizobia. As the effectiveness of rhizobia begins to decline, the host plant relies increasingly on soil nitrogen to satisfy its nutritional requirements. As pH_{Ca} declines below 5.0, plants may utilise more soil nitrogen than they contribute via nitrogen fixation.

For all the regions surveyed, soil pH_{Ca} was less than 5.5 in the top 10cm meaning there is likely to be some impediment to the optimisation of nitrogen fixation. The surface 10cm of the south east cropping paddocks and the 5-10cm layers of the pasture paddocks in the central east and south east were less than 5.0 (and as low as 4.6 and 4.7 in the crop and pasture paddocks of the south east growing regions, respectively) indicating nitrogen fixation may be severely constrained in these soils.

Management of soil acidity

Approximately one-third of growers surveyed had applied lime in the last five years to one or both paddocks sampled on their farm. Forty-five percent of growers surveyed indicated they had a specific target soil pH for one or both of their sampled paddocks with 80% nominating a target $pH_{Ca} \geq$ 5.5. Where lime was used, the application rates varied from 1000-3000kg/ha. Less than 20% of growers who applied lime practised full incorporation to a depth of 10cm. The majority relied on incorporation of applied lime at sowing or use of a speed tiller for incorporation.

Improving management of soil acidity

It is clear from the survey results that soil acidity is a significant issue across the growing regions sampled. There is a moderate level of awareness of target pH for optimising legume growth. Of those growers who nominate a target soil pH, most aim to achieve a soil pH that is suitable to achieve nitrogen fixation. Of the paddocks tested, most would generally benefit from an increase in soil pH in the surface 10cm of the profile to improve legume growth and nitrogen fixation. Where possible and practicable, greater use of full incorporation when liming would assist growers in reaching their soil pH targets in the surface 10cm. In the most part, below a depth of 10cm, soil pH_{Ca} was 5.5 or greater.

Available phosphorus

Phosphorus availability varied between regions, soil depth and in some regions (central east and south west) between land use (Figure 2). Phosphorus availability was above critical in all regions and for all land uses in the 0-5cm soil layer. While phosphorus availability was significantly lower at 5-10cm than at 0-5cm, it was above critical in all cropping paddocks (except in the central west) and in pasture paddocks in the south east growing region. Overall, when averaged over the 0-10cm soil layer, the available phosphorus level was above critical in all except for the central west cropping paddocks where phosphorus availability was 95% of the critical level.

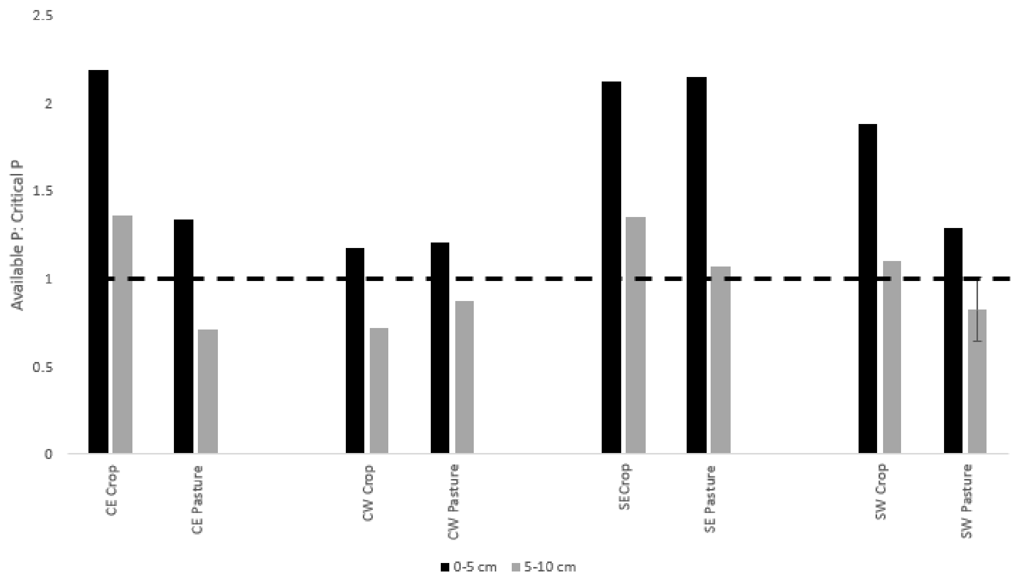

Figure 2. The ratio of available phosphorus (P; Colwell) and critical phosphorus based on phosphorus buffering index for crop and pasture paddocks in the 0-5 and 5-10cm soil layers of the central east, central west, south east and south west growing regions.

Implications of phosphorus availability for legume growth

Phosphorus is critical to drive plant growth and for the formation and maintenance of an effective symbiosis. Therefore, ensuring sufficient phosphorus is available is critical in achieving nitrogen fixation targets. However, it must be remembered that there are other macro and micronutrients that are also essential in supporting legume growth and nitrogen fixation. Surplus phosphorus does not compensate for deficiencies in other nutrients essential for plant growth and rhizobia survival and function.

Phosphorus management

Averaged across all cropping paddocks surveyed (except in the central west growing region), phosphorus levels averaged over the 0-10cm soil layer were 50-75% above the level considered critical to support optimal production. All pasture paddocks had at least critical phosphorus levels available in the surface 10cm of soil with pasture paddocks in the south east growing region having levels 50% above critical.

For pasture paddocks, there is unlikely to be any production benefit attributable to increasing soil phosphorus levels given the current levels whilst they remain under pasture. For cropping paddocks, phosphorus is generally well in excess of requirements, but high concentrations in the surface 5cm of the profile pose some production implications for grain legumes when sown at depths of 5cm or greater. This may also apply to pasture paddocks coming back into crop.

While deeper banding of phosphorus fertiliser may overcome shortages of phosphorus for deeply drilled seed, long term efficiencies also require consideration. It is clear from the survey results that there is generally luxury availability of phosphorus in the surface 5cm. Further, in the majority of paddocks sampled, soil acidity was an issue in the surface 10 cm. Rapid amelioration of soil acidity to 10cm requires full incorporation of lime to 10cm. This practice would also redistribute phosphorus throughout that section of the profile, overcoming any phosphorus and soil pH stratification issues.

Available sulphur

Sulphur availability varied with depth, and in the central west and south west growing regions between land use, with pastures having significantly lower levels of available sulphur than crop paddocks (Figure 3). On average, cropping paddocks had sufficient availability of sulphur in the surface 10cm (≥ 8mg/kg). However, for pastures, sulphur was deficient in the surface 10cm in all regions except the south east. There was no evidence of sulphur accumulation in any section of the soil profiles sampled (that is, to 30cm).

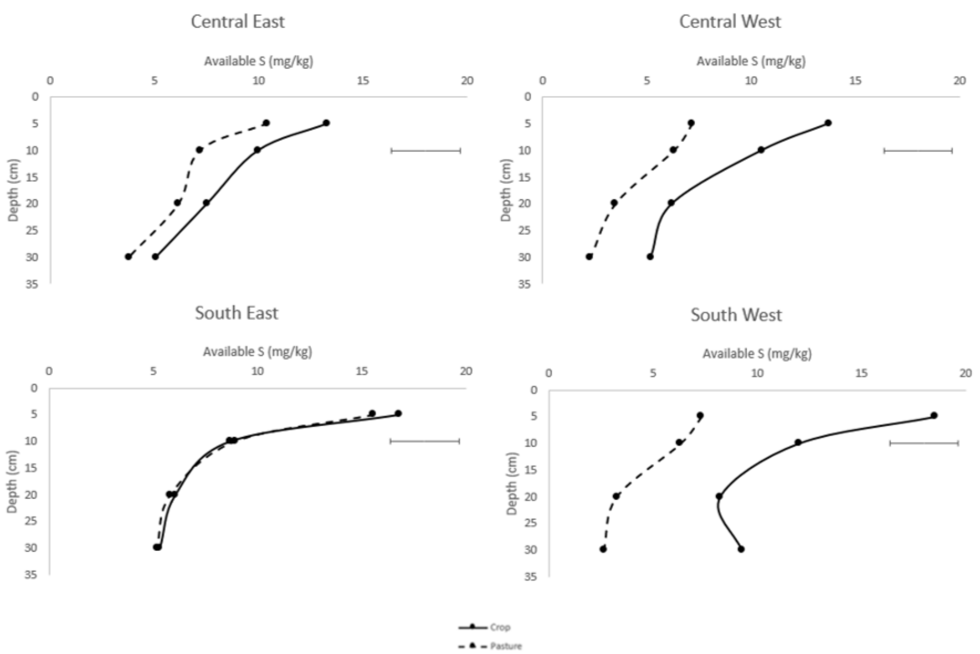

Figure 3. Available sulphur (S mg/kg; KCl-40) for crop and pasture paddocks sampled in the central east, central west, south east and south west northern GRDC growing regions. LSD at P<0.05 indicated.

Implications of sulphur availability for legume growth

Sulphur is a key nutrient required by legumes and rhizobia and is involved in the formation of an effective symbiosis and the conversion of atmospheric nitrogen to 'fixed' nitrogen. The survey results suggest that sulphur deficiency is unlikely to be limiting in paddocks currently used for cropping. However, for pastures, soil sulphur levels were generally much lower than in cropping paddocks which may impact on legume growth and nitrogen fixation.

Sulphur management

Monoammonium phosphate (MAP) was the most commonly used fertiliser on cropping paddocks (≥ 85% of respondents). However, more than 50% of cropping paddocks had also received an application of some source of sulphur over the past four years which may account for the relatively high sulphur availability in paddocks currently in crop. In contrast, for pasture paddocks in the central east, central west and the south west, fertiliser use was much more sporadic. In some regions, up to 75% of pastures had received no fertiliser in the three years prior to sampling. Where pastures were fertilised, it was predominately with MAP. Reduced fertiliser input and use of low sulphur fertilisers would explain the differences in sulphur levels between crop and pasture paddocks in these regions.

Potassium

Less than 5% of paddocks surveyed had potassium levels less than that considered adequate for the given soil type in the paddock.

Organic carbon

Soil organic carbon concentrations decreased significantly with depth and were significantly different between regions. However, with the exception of the south east, there was little difference between crop and pasture paddocks within regions (Figure 4). Soil organic carbon concentrations in the surface 10cm were lower in the central west than in other regions. In the south east, soil organic carbon concentrations in the 0-5 and -10cm soil layers were significantly higher in pasture compared to crop paddocks. Soil organic carbon concentrations were generally lower in the lower rainfall (central west and south west) regions for each respective land use than in the higher rainfall regions.

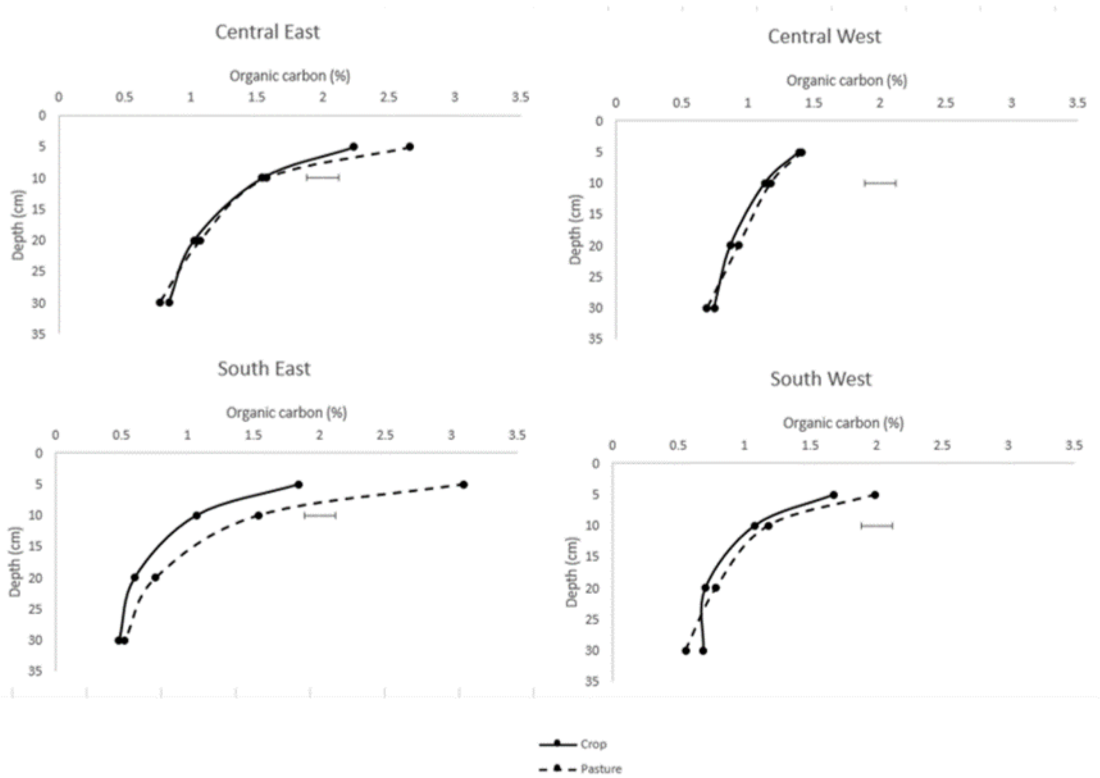

Figure 4. Soil organic carbon (%) for crop and pasture paddocks in the central east, central west, south east and south west GRDC northern growing regions. LSD at P<0.05 indicated.

Organic carbon implications for legume growth

Soil organic carbon concentration is an indicator of soil health; specifically, the soils ability to store, cycle and supply plant available nutrients. It is also correlated to soil structural properties including water holding capacity and infiltration. Increasing soil organic carbon concentration underpins plant and rhizobia growth and function, and can mitigate issues such as surface crusting that impedes emergence of newly sown crops and pastures.

Organic carbon management

Approximately 40% of growers surveyed nominated targeting organic carbon levels on 1.2-2.5% for their soils with a similar percentage of growers actively monitoring their soil organic carbon levels. The vast majority of growers (>80%) maintained stubble over summer and where pastures were part of their farming system, aimed to maintain at least 70% ground cover year round.

Herbicides

Herbicides and herbicide residues can have a significant impact on grain and pasture legume performance and their capacity to nodulate and fix nitrogen. The analysis of the survey data on herbicide use is in its preliminary stages. However, from the analysis so far, up to 40% of crop paddocks included in the survey were at risk of having residues that would impact the performance of legumes sown in the year following the crop based on herbicide application rates, timing of application and requirements required (e.g. time, rainfall, soil moisture) for plant back. In pasture paddocks, more than 20% of paddocks had herbicides applied during the pasture phase that would likely have a detrimental impact on legume function.

Conclusions

There are soil and management issues likely to constrain growth and nitrogen fixation of grain and pasture legumes throughout the four GRDC northern region growing zones surveyed. Soil acidity is widespread and likely to be placing restrictions on host legume growth and/or the development and maintenance of an effective symbiosis. The issue appears most severe in the south east growing region. While around 35% of growers have a specified soil pH_{Ca} target of >5.5, the way that strategies to manage soil acidity are applied requires change to rapidly ameliorate soil acidity in the surface 10cm of soil. Specifically, growers need to consider full incorporation of lime rather than incorporation by sowing or topdressing alone which is currently the most widespread practice. Strategic incorporation would also assist in alleviating the discrepancy in phosphorus availability between the 0-5 and 5-10cm soil layers which may currently limit performance of grain legumes when sown at > 5cm. Overall, phosphorus levels are generally above critical levels required for optimum production. Sulphur levels in cropping paddocks were generally adequate but deficient in pasture paddocks in the majority of regions, which reflects fertiliser forms used in pastures. While management surveys are only partially analysed, it is clear that herbicide residues pose a risk in a large proportion of paddocks and for established pastures, herbicides are used within the growing season that are likely to impact legume growth and nitrogen fixation. In summary, it appears there is scope to consider reapportioning management inputs to address issues that may be constraining legume productivity, specifically allocation of some expenditure to address soil acidity given soil phosphorus levels are generally at or well beyond critical levels.

Acknowledgements

The authors would like to acknowledge and are grateful for funding provided by GRDC through DAN1901 002 RTX *Increasing the effectiveness of nitrogen fixation in pulses through improved rhizobial strains in the GRDC northern region*. Further funding for the findings reported in this paper were provided by the Department of Agriculture and Water Resources, GRDC, MLA and AWI through project code 9175959 *Dryland legume pasture systems*. Additional funding provided by the Graham Centre for Agricultural Innovation, Central West Local Land Services, Central Tablelands Local Land Services and Central West Farming Systems.

The authors would also acknowledge the participation of all growers involved in the survey and we particularly thank them for providing information on the management of their paddocks.

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