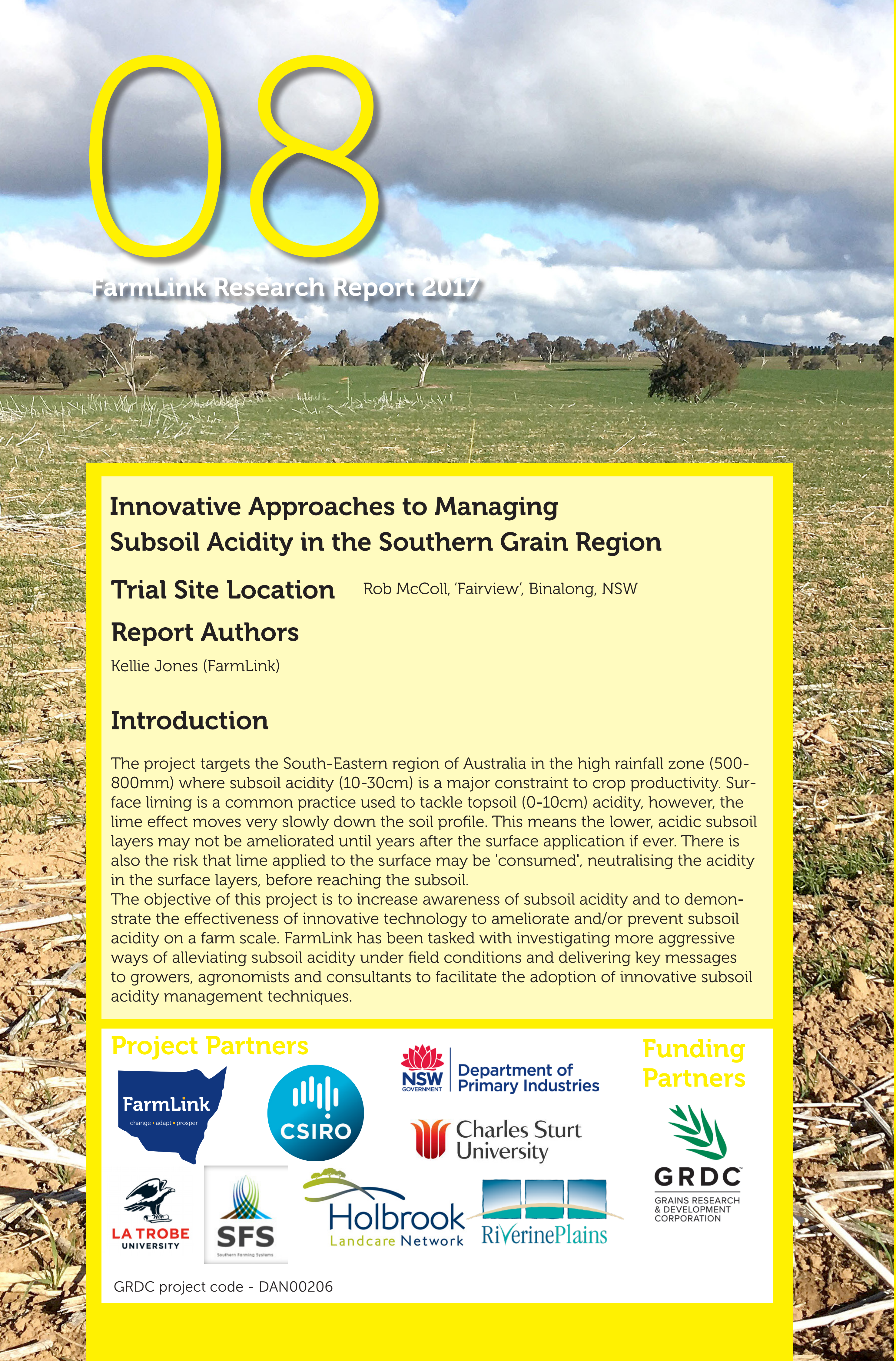

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FarmLink Research Report 2017

Innovative Approaches to Managing Subsoil Acidity in the Southern Grain Region

Trial Site Location

Rob McColl, 'Fairview', Binalong, NSW

Report Authors

Kellie Jones (FarmLink)

Introduction

The project targets the South-Eastern region of Australia in the high rainfall zone (500-800mm) where subsoil acidity (10-30cm) is a major constraint to crop productivity. Surface liming is a common practice used to tackle topsoil (0-10cm) acidity, however, the lime effect moves very slowly down the soil profile. This means the lower, acidic subsoil layers may not be ameliorated until years after the surface application if ever. There is also the risk that lime applied to the surface may be 'consumed', neutralising the acidity in the surface layers, before reaching the subsoil.

The objective of this project is to increase awareness of subsoil acidity and to demonstrate the effectiveness of innovative technology to ameliorate and/or prevent subsoil acidity on a farm scale. FarmLink has been tasked with investigating more aggressive ways of alleviating subsoil acidity under field conditions and delivering key messages to growers, agronomists and consultants to facilitate the adoption of innovative subsoil acidity management techniques.

Project Partners

FarmLink change • adapt • prosper

CSIRO

NSW Government Department of Primary Industries

Charles Sturt University

La Trobe University

SFS Southern Farming Systems

Holbrook Landcare Network

RiverinePlains

Funding Partners

GRDC Grains Research & Development Corporation

GRDC project code - DAN00206

Objectives

FarmLink's role is to establish two paddock scale replicated experiments to –

- Increase awareness of subsoil acidity
- Demonstrate effectiveness of innovative technology to ameliorate and/or prevent subsoil acidity on a farm scale

Method

Site 1 – Binalong, established 2016
One of the two of our large-scale on-farm experiment sites was established in the east of the FarmLink region in Binalong, NSW, in late February 2016. The site is located in the high rainfall zone (HRZ), with an average annual rainfall of 647mm. Sites were selected with the following target soil characteristics -

- Target sub-surface soil acidity
  - 0-10cm: pH ($CaCl_2$) 4.0-4.5. If limed, preferring <5.0%
  - 10-20cm: pH ($CaCl_2$) < 4.3, exchangeable Al% >20%
  - 20-30cm: pH ($CaCl_2$) < 4.6, exchangeable Al% >10%
- Location
  - High annual rainfall >500mm
  - Flat, uniform
  - Cropped for three consecutive years

The paddock is severely acidic and a high exchangeable aluminium level, fitting the trial site selection criteria perfectly.
The experiment included four treatments replicated three times (see *Appendix* for trial layout). The four treatments include surface liming, deep ripping, deep ripping with lime and deep ripping with an organic amendment, lucerne pellets were selected as the organic amendment. See *Table 1* for a more detailed description of the treatments. The treatments were implemented in the first year of the trial, with the site to be monitored for three years (2016-2018). The second year of monitoring was completed in 2017.

Table 1. treatments and descriptions for Binalong site implemented in 2016

	Treatments	**Description**
1	Surface liming	No lime was added due to the site receiving 3.5t/ha of surface lime in 2015. As we can see in Table 2, the pH in 0-10cm is 5.75 which is close to the target pH of 5.5.
2	Deep ripping only	Ripping occurred at a depth of 30cm and at width 50 cm between rippers. The surface was not limed due to liming in 2015.
3	Deep ripping + lime	2.6 t/ha of lime was placed at 10-30cm to target subsoil acidity.
4	Deep ripping + organic amendment	As above with organic amendment, i.e lucerne pellets at 10t/ha.

The treatments were implemented using a dual depth delivery (3-D) ripping machine designed and fabricated by NSW Department of Primary Industries. The 3-D ripping machine allows lime and other organic amendments to be accurately placed at two depths from 10–30cm. After the treatments were applied in 2016, the grower then sowed 970CL grazing canola at 3kg/ha on 300mm spacings at a 45°C angle to the deep rip lines. This was to ensure the seeder did not sow directly over the rip lines and it eliminated the need for the commercial size seeder having to be on 250mm row spacings. The same principle was used in 2017, when Spitfire wheat was sown at a rate of 70kg/ha.

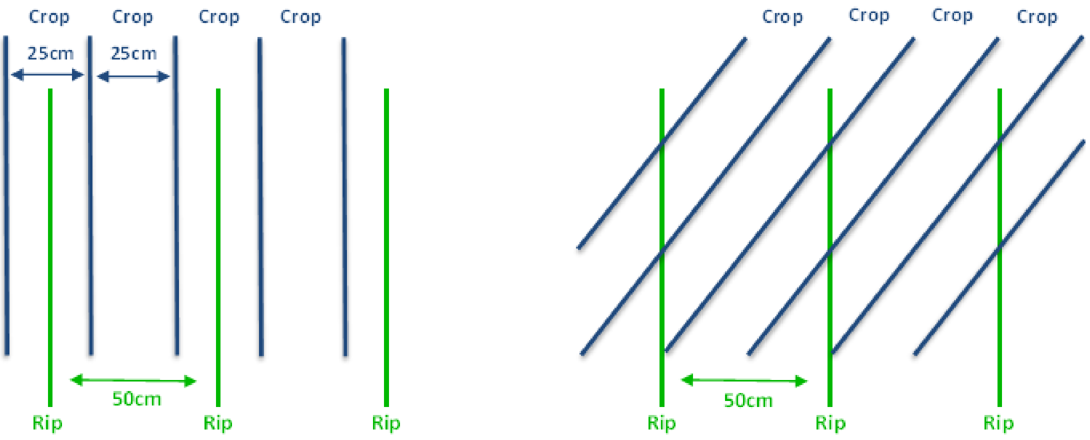


Figure 1. Initial crop sowing plan (left) vs current plan (right)

Another farm scale site will be set up at the beginning of 2019. The site will have the same selection criteria, treatments and assessments. Several assessments will be undertaken over three cropping seasons, using both statistical and observational methods. These assessments include; emergence counts, anthesis and harvest dry matter cuts, header yield data, grain quality testing and initial and final soil sampling.

Binalong Results

Below in *Figure 2*, the pH ($CaCl_2$) of the 0-10cm surface layer was 5.8, then dropped to 4.2 at a depth of 10-30cm. Similar to the exchangeable aluminium pattern, the pH began to increase below the 30cm mark. The exchangeable aluminium percent spiked dramatically to almost 19%, in the 10-20cm, then reduced to approximately 13% in the 20-30cm profile. Below 30cm, the exchangeable aluminium was below 1%.

In 2016, the surface liming treatment had the highest canola emergence count of 32.6 plants/m^2, while in 2017 the deep ripping treatment had the highest wheat emergence count of 111.3 plants/m^2 (Figure 3). The deep organic amendment treatment had the lowest canola emergence count of 18.5 plants/m^2 in 2016. In 2017, the deep liming treatment had the lowest wheat emergence counts of 99.3 plants/m^2.

Figure 4 shows surface liming had the lowest yield in 2016, yet it the highest yield in 2017. Deep liming had one of the highest yields in 2016 but had the lowest yield in 2017. The deep ripping, deep liming and organic amendment had similar yields, while surface liming had a yield of 4.5 t/ha, 3.9-4.0t/ha, in 2017.

Table 2 shows there is a substantial difference in canola oil and protein (2016) between the organic amendment treatment and the other three treatments. There was very little difference in wheat protein (2017) between all the treatments.

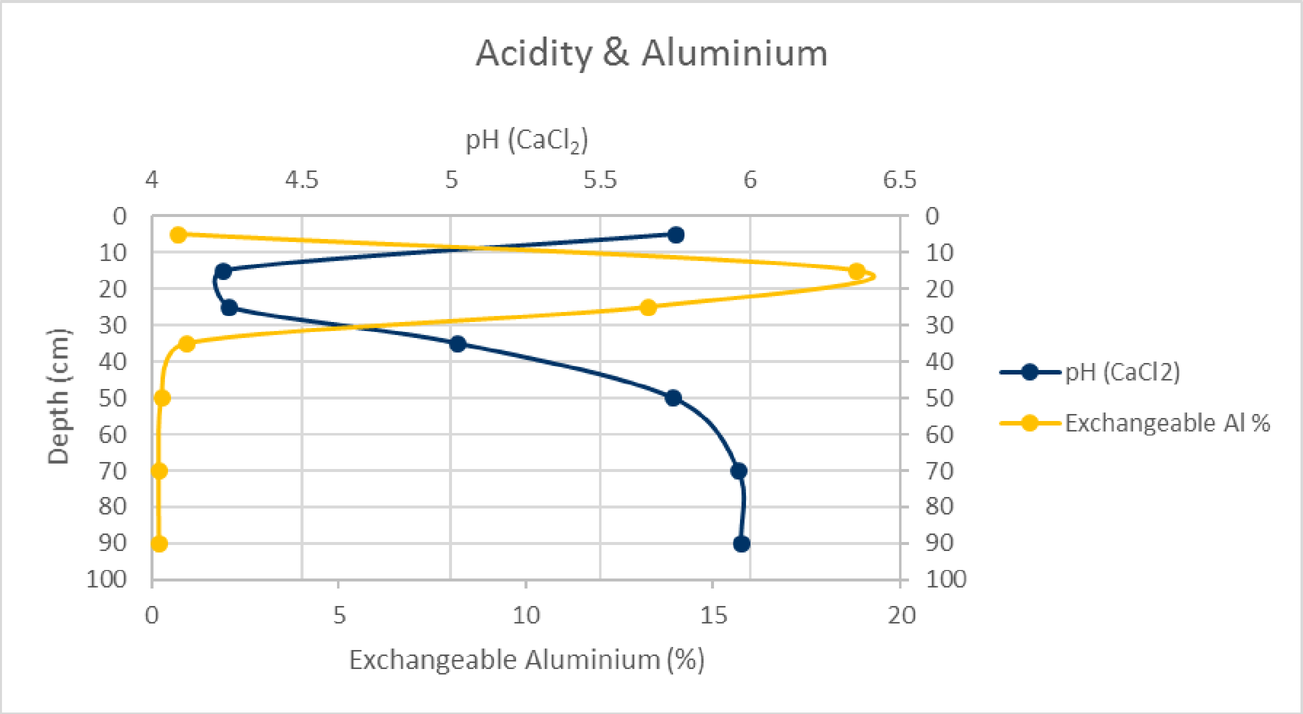


Figure 2. pH ($CaCl_2$) and exchangeable aluminium percentage from the initial soil samples averaged across the Binalong experimental site in 2016.

Discussion

Soil acidification is a natural process that is accelerated by agricultural activity, such as high yielding crops, product removal and fertilizer (Small, 2016). Soil becomes more acidic when plant material is removed from a paddock, because most of these products are alkaline and removal leaves the soil more acidic (Hollier & Reed, 2005). Acidification can decrease the availability of essential nutrients, while increasing the impact of toxic elements (Hollier & Reed, 2005). This subsequently reduces plant production. There are also other disadvantages such as decline in soil structure and effect on essential soil biological functions (Hollier & Reed, 2005). The task of alleviating sub soil acidity cannot be solved with the standard practice of surface liming because lime moves slowly through the soil profile, the alkalinity will most likely be

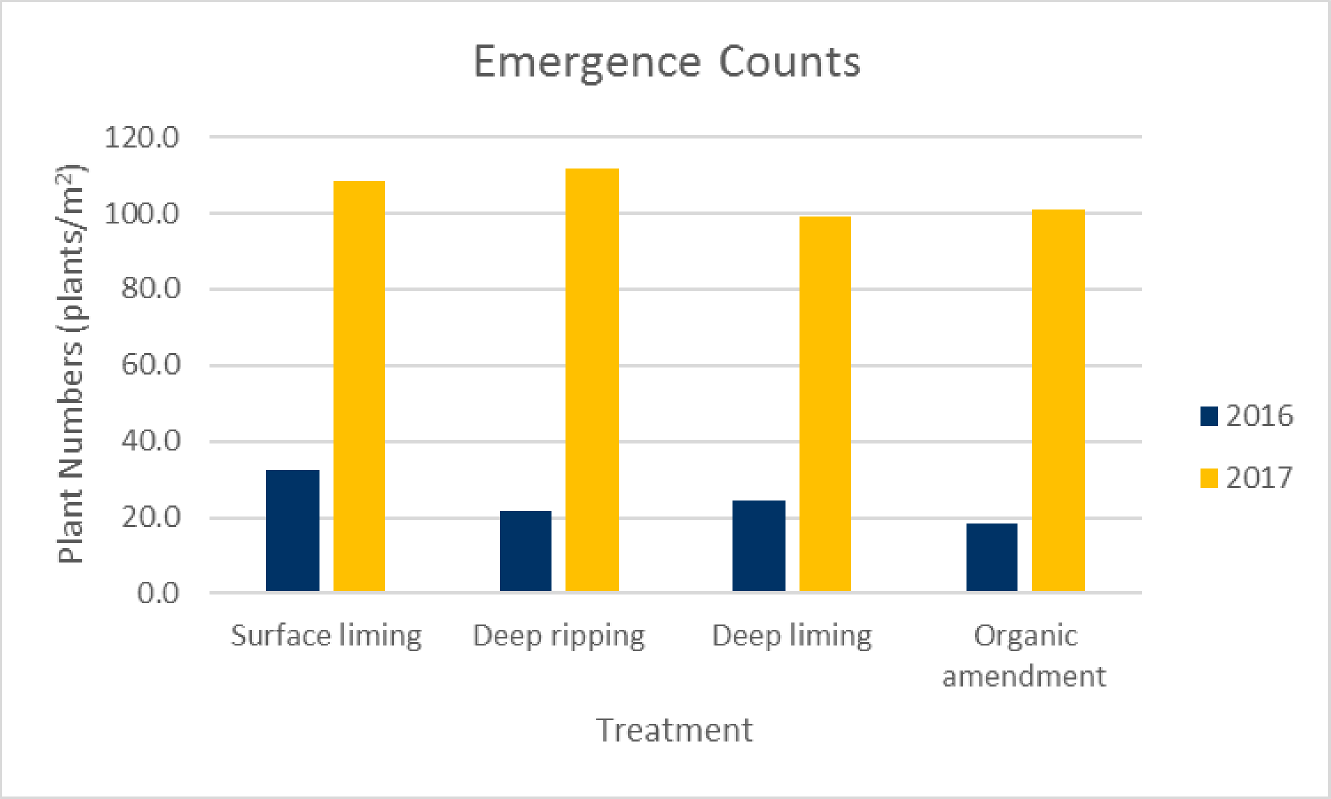


Figure 3. Emergence counts taken in 2016 (canola) and 2017 (wheat)

used up prior to reaching the acidic sub soil layers.

Baseline soil samples were taken at the beginning of the trial (*Figure 2*), prior to treatments being implemented. Samples were collected in 10 centimetre increments to a depth of 40 centimetres, and from there increased to 20 centimetre increments to a depth of 1 metre. The samples were analysed for exchangeable aluminium percentage and pH (calcium chloride method). The pH began at 5.8 in the top 10cm of top soil, but it quickly dropped to 4.2 and 4.3 at 10-20cm and 20-30cm. Then as expected, the pH increased below the 30cm depth. Producers should aim for a top soil (0-10cm) pH ($CaCl_2$) of 5 or above and a subsoil (10-30cm) pH ($CaCl_2$) of 4.8 or higher (Small 2016). Therefore, it's important to test and monitor soil

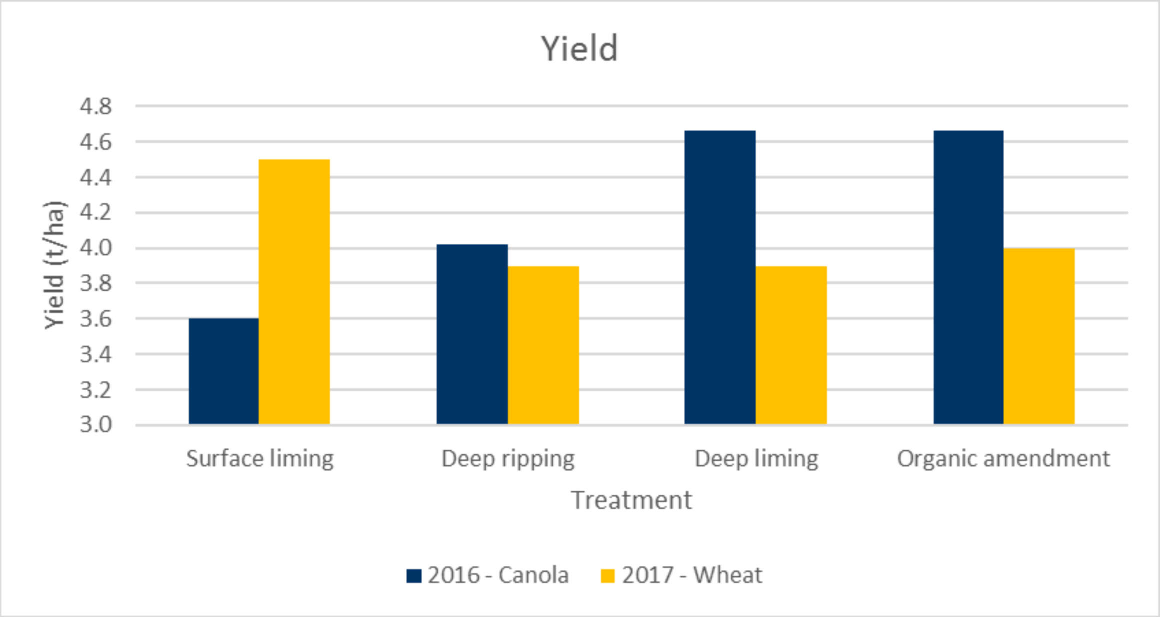


Figure 4. 2016 (canola) and 2017 (wheat) treatment yields.

Table 2. 2016 & 2017 grain quality, canola oil content (%) & grain protein (%) and wheat protein (%).

	Canola - 2016	Canola – 2016	Wheat - 2017
Treatment	Average Oil (%)	Average Protein (%)	Average Protein (%)
Surface liming	46.4	18.87	14.4
Deep ripping	46.5	19.07	14.8
Deep liming	46.1	19.43	14.2
Organic amendment	42.8	22.77	14.5

down to at least 30cm, rather than the standard practice of 0-10cm. Field test kits are an easy and inexpensive option to get a rough indication if there is a change in pH down the soil profile. The exchangeable aluminium was very low in the 0-10cm soil layer, then increased drastically to approximately 19% at the depth of 10-20cm. The aluminium level began to decrease to 13% at 20-30cm, then dropped back down to less than 1% as the pH increased to above 5. An exchangeable aluminium percentage above 5% will begin to effect root growth of acid sensitive species. A small decline in pH in soils where aluminium is present can result in a large increase in exchangeable aluminium (Upjohn et al 2005). Crops sensitive to aluminium will have poor root development, resulting in restricted water and nutrient access from deeper in the soil profile.

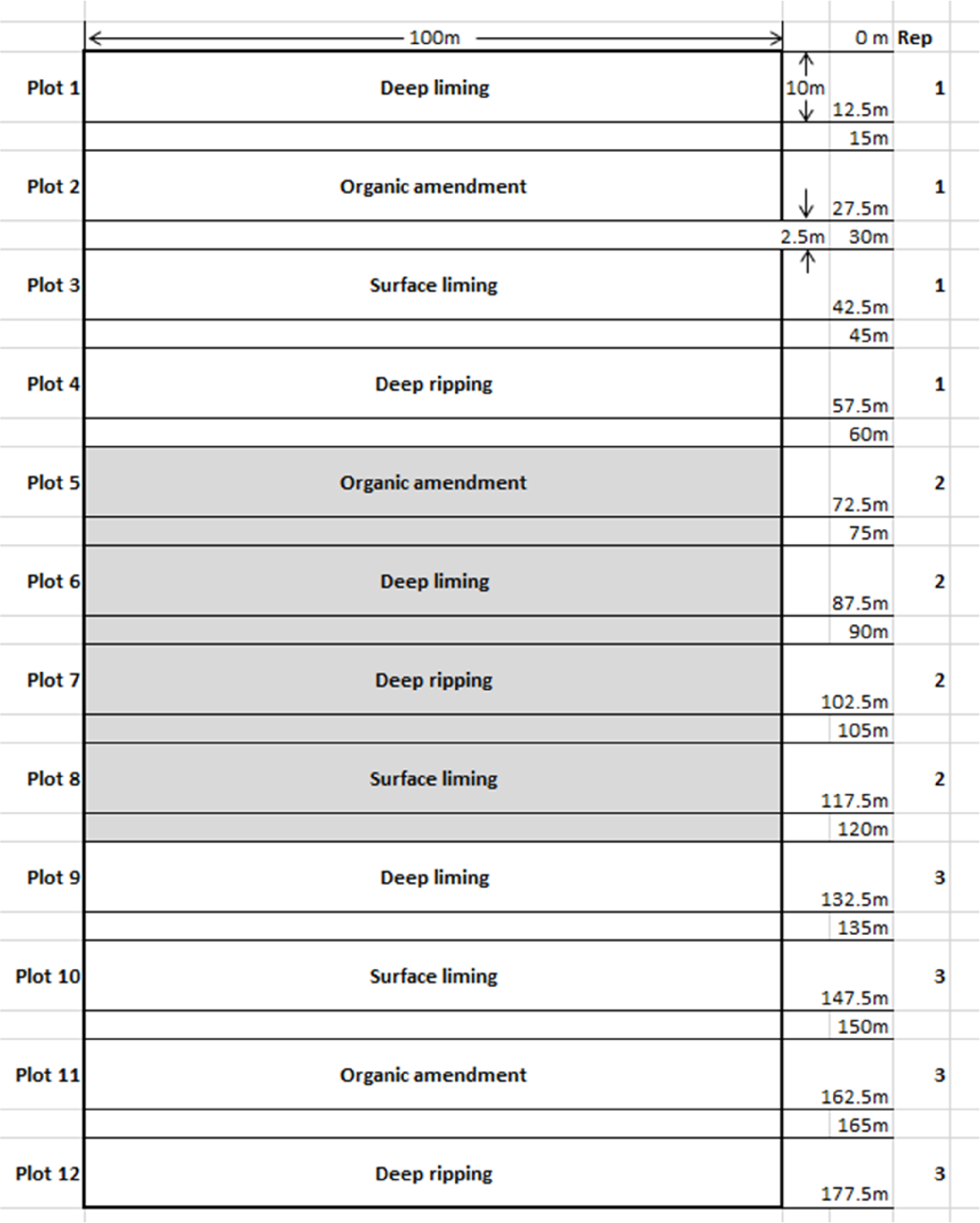
No emergence trend formed over 2016 and 2017 when comparing treatments for either canola or wheat *(Table 2)*. In 2016, the organic amendment treatment had the lowest plant emergence, it had 43% less plants than the surfacing liming treatment which had the highest emergence. There was only 11% difference between deep ripping, the top performing treatment in 2017, and deep liming, the poorest performing treatment in terms of plant emergence.

Figure 4 shows an inverse relationship between the canola yield in 2016 and the wheat yield from 2017. The surface liming treatment had the lowest yield in 2016 and the highest yield in 2017. The surface liming treatment was the only treatment that had a positive influence yield in 2017, the deep lime, deep rip and organic amendment all yielded approximately 4t/ha.

In 2016 there was a clear treatment effect in canola oil content. All treatments had an average canola oil content of 46% or higher, except for the organic amendment treatment which had an average oil content of 42.8%. Protein levels generally work in an inverse relationship to oil content (GRDC 2009). There was very little difference in average protein levels across all the treatments in 2017. There was only 0.6 difference between the highest and lowest average protein in 2017.

Final soil samples will be taken at the conclusion of the experiment in 2018, after harvest. The protocol for the final samples will be the same as the protocol for the initial samples. Except, cores will be taken on rip line and in-between the rip lines in the strips that were ripped. The initial soil sample results will be separated into treatments for the comparison in the final report.

There are many variables that can influence the results, such as crop type, seasonal climate, various environmental pressures and how long the treatments continue to effect results after the first and only application. A further year of research and analysis from this site and other sites will give strength to these findings.



	100m		0 m	Rep
Plot 1	**Deep liming**	10m	12.5m	**1**
			15m	
Plot 2	**Organic amendment**		27.5m	**1**
		2.5m	30m	
Plot 3	**Surface liming**		42.5m	**1**
			45m	
Plot 4	**Deep ripping**		57.5m	**1**
			60m	
Plot 5	**Organic amendment**		72.5m	**2**
			75m	
Plot 6	**Deep liming**		87.5m	**2**
			90m	
Plot 7	**Deep ripping**		102.5m	**2**
			105m	
Plot 8	**Surface liming**		117.5m	**2**
			120m	
Plot 9	**Deep liming**		132.5m	**3**
			135m	
Plot 10	**Surface liming**		147.5m	**3**
			150m	
Plot 11	**Organic amendment**		162.5m	**3**
			165m	
Plot 12	**Deep ripping**		177.5m	**3**

Figure A1. Large scale site layout.

Figure A2. Aerial view of the Binalong site, taken 2016.

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REPORT TWO

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http://www.dpi.nsw.gov.au/agriculture/soils/acidity

NSW GOVERNMENT
Department of Primary Industries

This article provides an overview of this major GRDC funded project that commenced in 2015. This issue also highlights the framework and key features of the experimental design for the long-term field experiment near Cootamundra in southern NSW.

Project Background

Subsoil acidity is a major constraint to crop productivity in the high rainfall zone (500–800 mm) of south-eastern Australia. The surface application of lime is commonly used to combat topsoil acidity. However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after years of surface application. In addition, at the current commercial rates of about 2.5 t/ha, most of the added alkalinity is consumed in the topsoil and has limited effect on neutralizing subsoil acidity or counteracting subsoil acidification.

Experimentation

A long-term field experiment was established in 2016 at Dirnaseer, west of Cootamundra, NSW, to monitor long-term soil chemical, physical and biological processes. A range of laboratory soil incubation studies and glasshouse experiments will be conducted under controlled environments to compare effects of various combinations of soil amendments on soil amelioration processes. These inform the most efficient soil amendments, optimum rates and best placements in the soil profile for current and future field experiments.

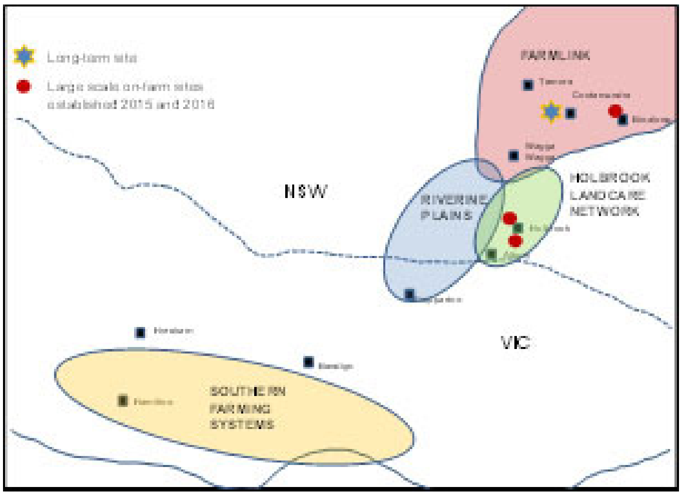
A series of large scale field experiments will also be conducted on farmers' paddocks to demonstrate the benefits of the most effective soil amendments and innovative technologies across different soil and climate conditions in NSW and Victoria.

Aim

This project will investigate innovative technology to deliver novel soil amendments, such as calcium nitrate and magnesium silicate, lucerne pellets as well as lime, directly into the subsoil (10-30 cm) to ameliorate acidity.

Target region

The project covers major high rainfall cropping areas from southern NSW to south-west Victoria.



Framework of long-term field experiment

'Ferndale', Dirnaseer, west of Cootamundra, NSW

Objectives

- To manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability.
- To study soil processes and measure the long-term changes in soil chemical, physical and biological properties.

Treatments and design

- Four crops in sequence
- Six soil amendments
    - Control, no amendment
    - Surface liming, target pH 5.5 at 0-10 cm
    - Deep ripping only (30 cm depth)
    - Deep ripping + lime, target pH 5.0 at 0-30cm
    - Deep ripping + lucerne pellets (15 t/ha)
    - Deep ripping + lime + lucerne pellets
- Three replicates in a split-plot design

Key features

- Phased design. There are 4 crops in the rotation, arranged in a fully phased design. Each crop will appear once in any given year a) to assess responses of different crops to different soil amendments; b) to compare treatment effect, taking account of seasonal variation.
- Crop rotation cycle. One crop rotation cycle will take four years to complete with the

Table 1. Crop rotation cycle and phases

		Phase 1	Phase 2	Phase 3	Phase 4
Year 1	2016	**W1**	C2	B3	F4
Year 2	2017	C2	B3	F4	**W1**
Year 3	2018	B3	F4	**W1**	C2
Year 4	2019	F4	**W1**	C2	B3
Year 5	2020	**W1**	C2	B3	F4
Year 6	2021	C2	B3	F4	**W1**
Year 7	2022	B3	F4	**W1**	C2
Year 8	2023	F4	**W1**	C2	B3
Year 9	2024	**W1**	C2	B3	F4
Year 10	2025	C2	B3	F4	**W1**
Year 11	2026	B3	F4	**W1**	C2
Year 12	2027	F4	**W1**	C2	B3
Year 13	2028	**W1**	C2	B3	F4
Year 14	2029	C2	B3	F4	**W1**
Year 15	2030	B3	F4	**W1**	C2
Year 16	2031	F4	**W1**	C2	B3

Crop code:

W1, crop at phase 1 as wheat; C2, crop at phase 2 as canola; B3, crop at phase 3 as barley; F4, crop at phase 4 as faba bean for early sowing, or field pea for late sowing.

crop sequence as wheat-canola-barley-grain legume.

- Soil amendment cycle. Soil amendments will be applied every 8 years in years 1 and 9, pending availability of funding.
- Soil samples. All soil samples will be archived for long-term storage.
- Data management. All data will be uploaded into the Katmandoo database.

Measurements

- Soil chemical properties
    - Deep soil coring at 10 cm intervals to 40 cm and 20 cm intervals from 40 to 100 cm
    - Shallow soil coring at 10 cm intervals to 40 cm
    - pH in $CaCl_2$; exchangeable Al, Ca, Mg, Mn, K and Na
    - Soil total C and N, organic C (Heanes)
    - Colwell P
- Soil physical properties
    - Particle size distribution
    - Soil aggregation stability
    - Penetrometer measurement
- Soil biological properties
    - Soil microbial diversity
    - Earthworm population and biomass
- Soil moisture and root depths
    - Neutron moisture meter measurements
    - Rooting depth and root density
- Agronomy measurements
    - Establishment count
    - Tiller count
    - Anthesis DM
    - Harvest DM
    - Grain yield and quality

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3-D Ripping Machine

A dual depth delivery (3-D) ripping machine has been built to provide accurate placement of soil amendments at two depths from 10 to 30 cm. This issue highlights some early observations from the long-term field site near Cootamundra in southern NSW, established in 2016.

Figure 1. The 3-D Ripping Machine. The coulters in front of each ripping tyne and the back roller produce a flat seedbed. Photo by Guangdi Li

Key features

- Dual amendment boxes: two boxes to hold lime (up to 150 kg) and organic amendment (up to 1 tonne) separately
- Dual feeding systems: two feeding augers to deliver lime (up to 4 t/ha) and organic amendment (up to 20 t/ha) simultaneously
- Dual delivery depths: two exit points and plates on each tyne to allow lime and/or organic amendment to be placed evenly from 10-30cm
- Dual metering systems: two separate fluted-roller metering systems with variable gear boxes to ensure accurate application rates as required
- Base unit: Grizzly Ripper
- Ripping tyne: 5 tynes with 50 cm spacing
- Ripping depth: down to 50cm with 200 HP tractor.
- Front coulter: to break topsoil and prevent surface layer being lifted
- Back roller: to compress soil behind the ripper and leave a flat surface ready for sowing.

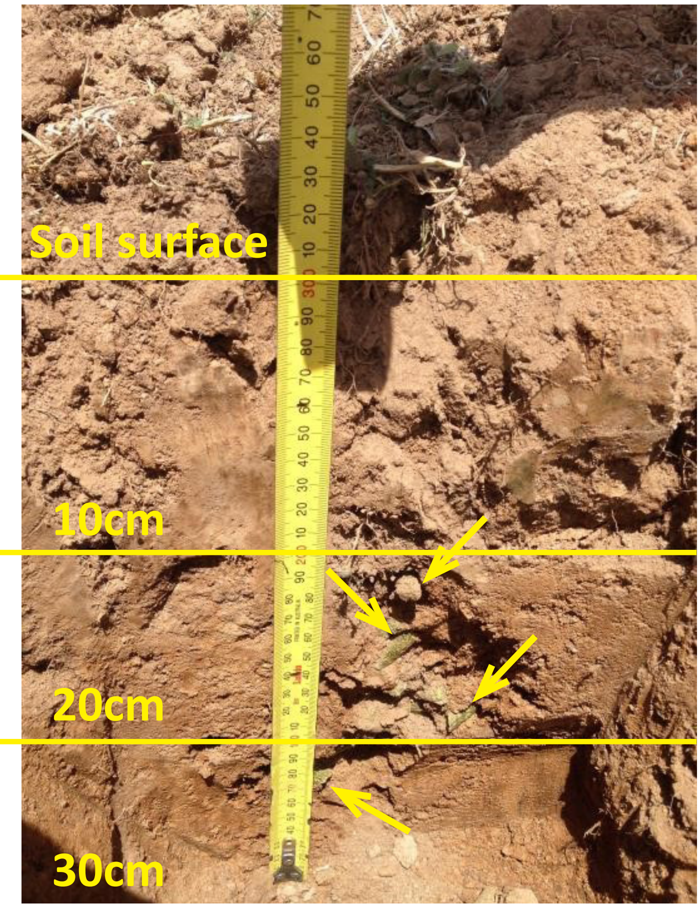


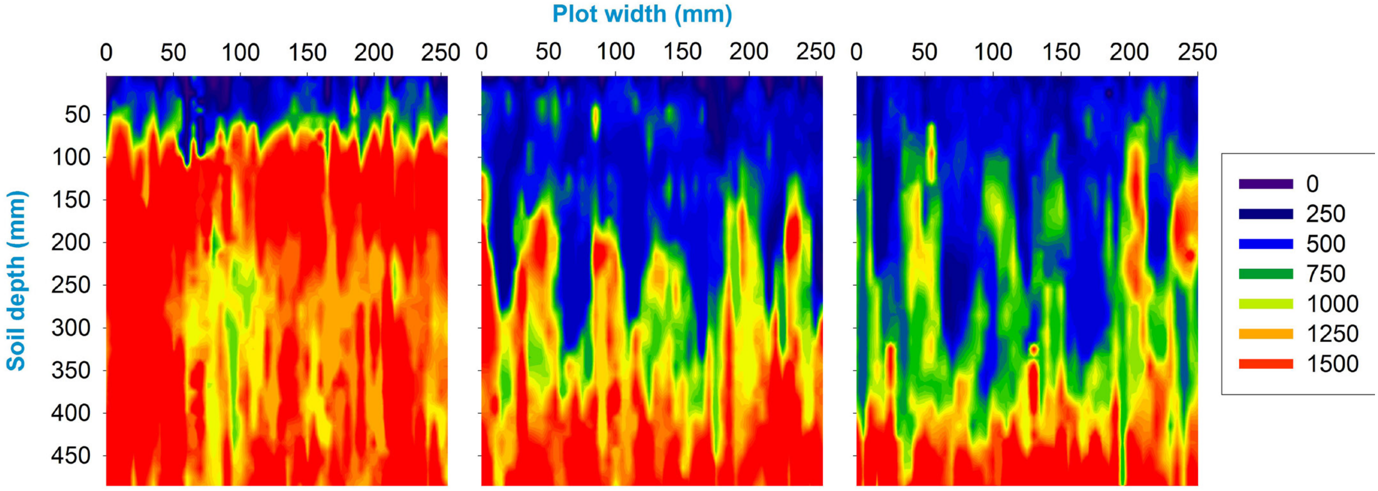
Figure 2. Dual delivery systems place lime and/or organic amendment at depths from 10 to 30 cm. Yellow arrows are pointing to lucerne pellets. Photo by Guangdi Li

Soil strength under amendments
'Ferndale', Dirnaseer, west of Cootamundra, NSW

Penetrometer readings

A penetrometer was used to test the soil strength 5 months after treatments were imposed. The contour map was produced from penetrometer readings at 50 mm intervals across a section of plot down to a depth of 485 mm (Figure 4).

- For the unripped treatment, there was an obvious compaction layer at 8-20 cm. The cultivation and sowing operation was at 0-8cm.
- For the ripped treatment, there was distinct ripping effect, showing rip lines at 50 cm intervals.
- For the ripped with lucerne pellets treatment, it seems the ripping effect was beyond the ripping depth (30 cm).
- The long-term ripping effect will be monitored over time.



a) Control (unripped)

b) Ripped

c) Ripped with lucerne pellets

Figure 2. Penetrometer readings (kPa) on plots under a) Control; b) Ripped and c) Ripped with lucerne pellets treatments (5 months after treatments were imposed)

Deep liming *Deep liming + lucerne pellets*

Figure 3. Gregory wheat plots on 29 August 2016. Crop was sown on 21 May 2016. Photo by Guangdi Li.

Initial crop responses

There were visible crop responses to soil amendments for wheat, barley and canola crops at the seedling stage in year 1. Deep ripping with lucerne pellets produced more seedling dry matter compared with the control treatment. The ripping only treatment also improved crop growth.

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Genetic potential for yield improvements on acid soils in Australia's major grain crops

A scoping study provides an overview of current knowledge of acid soil tolerance in the major winter crops species (wheat, barley, canola and pulses).The review listed known mechanisms and genes controlling Al and Mn tolerance and proposed strategies for improving tolerance in certain species.

Project background

Crop yields begin to be limited when soil pH falls below 5.0 in $CaCl_2$. Australia's major grain crops (wheat, barley, canola and pulses) continue to be affected by acid soils (Figure 1) and total losses to agriculture are estimated to be $900 to $1,585 million per annum (Hajkowicz 2005).

Acid soils present many stresses to plants but chief among them is aluminium (Al^{3+}) toxicity which inhibits root growth (Figure 2). Although acid soils can develop naturally, certain agricultural practices increase the rate of acidification. If left unmanaged acidification will degrade agricultural land and cause larger yield losses in the future.

The most effective management practice for slowing and even reversing acidification is the application of lime (calcium carbonate) but it can take years for the lime to correct pH in the subsoil below 10 cm. This is particularly true in minimum tillage production systems. Crops and cultivars with a greater tolerance to acid soils are important resources for farmers because they maintain production and income while amelioration efforts continue.

It is unlikely that the genetic yield potential of Australia's major crops on acid soils has been fully realised. Further increases in production could be achieved through standard breeding strategies, from wider crosses to related species and from genetic engineering (Ryan *et al*. 2011).

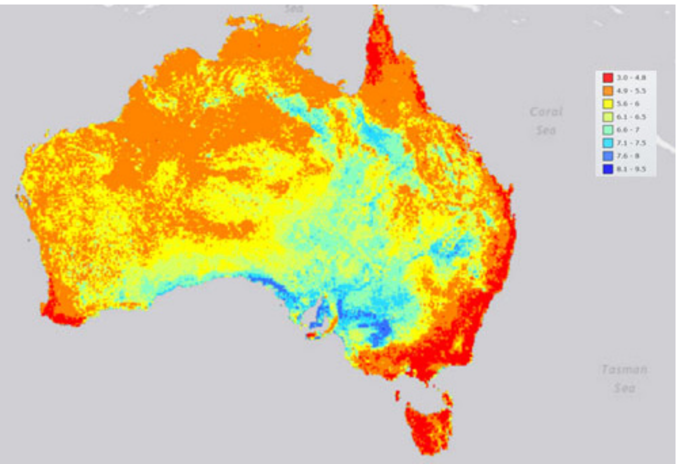

Figure 1. Distribution of acid soil in Australia. Data show the estimated value for soil pH at 5-15 cm depth. Source is the Soil and Landscape Grid of Australia (http://www.asris.csiro.au/viewer/TERN/)

Potential for improvement

- Bread wheat is Australia's largest crop so even small yield increases on acid soils can significantly impact production. Most cultivars are already reasonably tolerant to low pH because they possess the major gene for tolerance that controls the Al^{3+}-activated malate release from root tips. Further improvements might be possible by pyramiding other known QTL and by introducing genes from highly-tolerant cereals such as rye or triticale.
- Barley, Australia's second largest grain crop, is more sensitive to acid soils than wheat. Nevertheless there is some genotypic variation and breeders have exploited this variation to develop a commercial cultivar "Litmus". Litmus yielded significantly better than other elite barley cultivars on acid soils in Western Australia. More advanced material is currently being generated and this could expand the total area of barley cultivation.
- Durum wheat is among the most sensitive cereal species to acid soils. It shows very little genotypic variation in tolerance so cultivation

is restricted to non-acid regions of South Australia, Victoria and northern NSW. Although production is small compared to bread wheat durum it is a lucrative crop with strong market potential. Recent programs at CSIRO have successfully increased the acid tolerance of durum by introducing genes from hexaploid wheat (Han et al. 2016). These lines could raise production significantly by increasing yields and expanding the area under cultivation.

- Canola is Australia's third major grain crop and also more sensitive to acid soils than bread wheat. Genotypic variation for acid soil tolerance appears to be small and so breeding strategies to improve adaptation to acid soils may have limited success. However since canola is one of two genetically-modified crops currently grown in Australia biotechnology could be used to increase production on acid soils.
- Pulses have become popular choices for crop rotations. Substantial benefits would result from improving the acid soil-tolerance of pulses because, apart from the lupin species, most are sensitive or very sensitive to acid soils. Any improvement in the tolerance of chickpea, lentils, faba bean or field pea would be welcomed by farmers across Australia. Significant genotypic variation for acid soil-tolerance has been reported in most of these pulse species. Whether the cultivars grown in Australia have reached their genetic yield potential on acid soils is unknown and should be a priority for breeders.

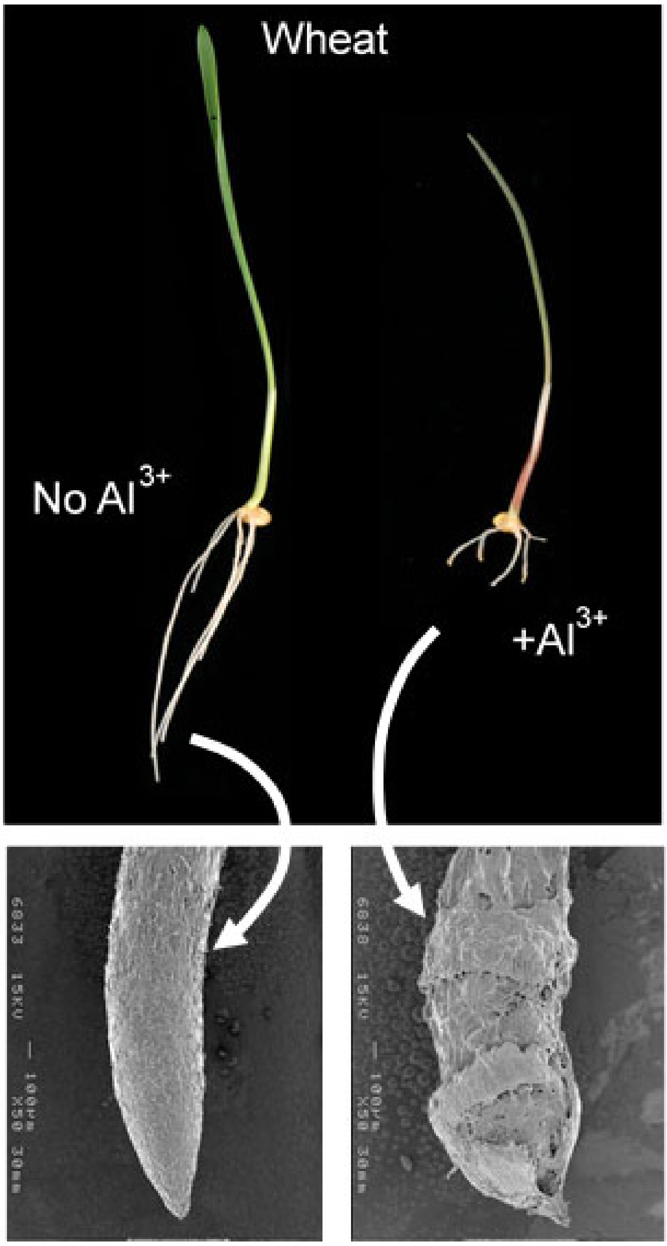

Figure 2. The Al^{3+} ions prevalent in acid soils inhibit root growth by damaging the root tips where cell division and elongation occurs (Micrographs by E. Delhaize)

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La Trobe University Component

La Trobe University is one of the key research partners in this major GRDC funded project which started in 2015. In this issue, we provide an overview of the laboratory and glasshouse experiments that the La Trobe University team will conduct over four years.

Project background

Subsoil acidity is a major limitation to crop productivity, primarily due to high concentrations of aluminium (Al) which limit root development and function. Innovative solutions to ameliorate subsoil acidity are needed since traditional application of lime on the soil surface is not effective at depth. Placement of ameliorants, including lime and/or organic materials, placed directly into acidic soil layers via deep ripping, is thought to be a promising approach.

The La Trobe team, led by Professor Caixian Tang, will conduct experiments to compare the effects of various organic and inorganic amendments, their rates and depth of placement on ameliorating soil acidity. The promising products, based on research results, will be recommended to field research team to implement in the field when available and if appropriate.

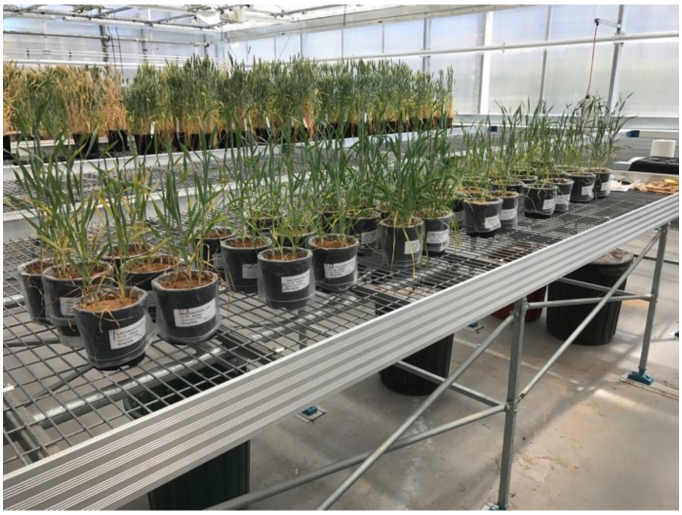

Figure 1. Glasshouse facility at La Trobe University. Photo by Clayton Butterly.

Photo by Clayton Butterly.

Experimental plan

Over the next 4 years, the La Trobe team will conduct a series glasshouse/laboratory experiments in the following areas:

- Evaluate the effectiveness of a range of inorganic (lime, gypsum and nutrients) and organic amendments (composts, animal wastes and crop residues) and their combinations to ameliorate subsoil acidity;
- Quantify the effectiveness of the amendments placed at various depths at different application rates with the best amendment treatments identified from previous screening experiments;
- Examine the effects of surface-applied lime alone or mixed with compost or gypsum on alkalinity movement in soil profiles and use a range of crop residues differing in ash alkalinity to examine their effects on the movement of surface applied lime to deep soil layers; and
- Assess the effectiveness of calcium nitrate alone and in combination with P and other nutrients in ameliorating subsoil acidity and to study the N use efficiency by crops with fertilizers placed at various depths.

Soils

In addition to soils with specific characteristics from both Victoria and New South Wales, the experiments conducted by the La Trobe team will utilize soils from the various field sites of the larger project, including the long-term field site at Dirnaseer, West of Cootamundra, NSW.

Experimental techniques

The La Trobe team will utilize their state-of-the art laboratory facilities at the Centre for AgriBioscience at the La Trobe University, Melbourne Campus. In particular they will;

- Conduct experiments in controlled environment rooms and automated glasshouses.
- Use Al sensitive (ES8) and tolerant (ET8) wheat cultivars to quantify crop responses to various soil amendments.

Figure 2. Laboratory facilities at La Trobe University. Photos by Clayton Butterly.

Figure 3. Typical acidic soil profile in Victoria. Photo by Clayton Butterly.

- Quantify changes in soil pH using 0.01 M CaCl2 extracts (1:5 soil:extract).
- Examine changes in dissolved organic carbon in soil extracts or leachates using an automated organic carbon analyser.
- Determine Al concentrations in soil extracts (0.01 M CaCl2) using inductively coupled plasma-optical emission spectroscopy (ICP-OES) and colourimetrically with pyrocatechol violet and the contribution of Al to the cation exchange capacity in amended soils.
- Assess changes in soil microbial biomass carbon using chloroform fumigation-extraction combined with organic carbon analysis.
- Estimate amendment decomposition rates by measuring temporal patterns of CO_2 release using an infra-red gas analyser.
- Measure crop biomass and root morphology (root length, diameter and volume) using a WinRHIZO Pro scanning system.
- Characterise the nutrient and Al content of root and shoot biomass using ICP-OES following digestion of plant material with nitric-perchloric acids. ■

NSW GOVERNMENT Department of Primary Industries

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http://www.dpi.nsw.gov.au/agriculture/soils/acidity

Charles Sturt University Component

Charles Sturt University (CSU) is one of the research partners in this major GRDC funded project, led by NSW Department of Primary Industries. This is an overview of the CSU component.

Subsoil acidity issues

Crop production in southern NSW is strongly constrained by subsurface and subsoil acidity, which in many cases are a direct result of soil acidification brought about by agriculture.

Although Al and Mn toxicity are the major constraints in acid soils and can severely restrict plant growth, they are not the only ones (Table 1).

Acid soil sensitive plants, such as canola and barley, grown in soils where the subsurface and or the subsoil is acidic, develop small and shallow root systems (Figure 1). Such poorly developed root systems restrict access to moisture and nutrients, particularly nitrate, from the subsurface soil thereby severely reducing the yield potential of the plant.

Liming can easily ameliorate soil acidity by increasing soil pH, eliminating Al toxicity and possibly reducing Mn toxicity. However, the current practice of only liming the soil surface layer does not result in amelioration of subsurface acidity.

Lime will only ameliorate the pH in the soil layer in which it has been incorporated and therefore can eliminate acid soil related stresses in that layer only. Liming of the lower acidic layers is a slow process, requiring the repeated application of lime to the surface layer for the alkalinity to move down the soil profile and ameliorate the subsurface acid layer. Thus, the combined use of liming with acid soils tolerant cultivars would provide, in the interim, maximised crop growth.

Therefore, there is a need to find alternative agronomic approaches and amendments to ameliorate soil acidity that develops at depth.

Figure 1. Differential response of Al tolerant (Dayton) and Al sensitive (Kearney) grown in limed (L, pHCaCl2 5.7) and unlimed (U, pHCaCl2 4.2) acid soil. Photo by Sergio Moroni.

Table 1. Major constrains to plant growth under acid soils conditions

Decrease in		
metal cation concentration	→	Mg, Ca and K deficiency
P and Mo solubility		P and Mo deficiency
Inhibition of		
metal cation uptake	→	Mg, Ca and K deficiency
root growth		Reduced nutrient and water uptake
Increase in		
leaching		Nutrient deficiency
H^+ concentration	→	H^+ toxicity
$Al3^+$ concentration		Al^{3+} toxicity
Mn^{2+} concentration		Mn^{2+} toxicity

Key research objectives

Over the duration of the project the CSU team will conduct a major field experiment and a series of laboratory and controlled environment experiments to determine the following:

- What is the mechanism by which selected organic and/or inorganic amendments ameliorate an acid soil?
- What is the level of tolerance to soil acidity among cereals, canola and pulses varieties currently available in the market?
- What is the interaction between crop × acid soil × soil amendments?

Lab/glasshouse experiments

- Quantifying responses of crop varieties in acid soils
- Quantifying the effectiveness of amendments in PVC columns with stratified acid soils layers
- Quantifying the crops × soil amendment interactions in acid soils

Field experiment

A sub-soil acidic site at Rutherglen will be used to quantify the ameliorative effect of lime, lucerne pellets, rock phosphate and magnesium silicate in the subsoil on crop performance and soil improvement. 🟨

Table 2. Soil treatments at the Rutherglen field site.

ID	Treatment	Description
1	Nil amendment	Control, no amendment
2	Rip only	Ripping to 30cm
3	Surface liming	Surface liming to pH5.5
4	Surface liming	Surface liming to pH5.0
5	Deep liming	Deep liming to pH5.0 to 30cm
6	Deep dolomite	Deep dolomite to pH5.0 to 30cm
7	Deep MgSi (High)	Deep MgSi at 8 t/ha
8	Deep MgSi (low)	Deep MgSi at 4 t/ha
9	Deep RPR (High)	Deep phosphate rock at 8 t/ha
10	Deep RPR (low)	Deep phosphate rock at 4 t/ha
11	Deep phosphorus	Deep P at 15 kg/ha
12	Deep lime+P	Deep liming + P at 15 kg/ha
13	Deep lucerne pellet1	Deep lucerne pellet at 15 t/ha
14	Deep lucerne pellet2	Deep lucerne pellet at 7.5 t/ha

Figure 2. Pot experiment at the glasshouse facilities at Charles Sturt University. Photo by Sergio Moroni.

Figure 3. Canola crop at the Rutherglen field site. Photo by Sergio Moroni.

REPORT SEVEN

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http://www.dpi.nsw.gov.au/agriculture/soils/acidity

NSW GOVERNMENT
Department of Primary Industries

Comparison of a range of amendments on alleviating aluminium and manganese toxicity in wheat

This issue covers an experiment that the La Trobe University team conducted to assess different soil amendments for their potential in ameliorating soil acidity.

Introduction

Soil acidity (pH<5.5 in calcium chloride) with aluminium (Al^{3+}) and manganese (Mn^{2+}) toxicities is a major constraint to global food production. In acid soils Al-toxicity inhibits root growth and function by interrupting root elongation and Mn toxicity limits shoot growth by interfering with a variety of biochemical pathways, including photosynthesis. Phosphorous (P) is often the most limiting macro nutrient in acidic soils. While lime application to increase pH is an effective practice, it is limited in treating soil acidity at depth, especially when applied at the surface.

In this study seventeen organic and inorganic amendments were evaluated in two contrasting soils to ameliorate soil acidity either due to their ability to directly bind exchangeable Al^{3+} and Mn^{2+}, increase pH directly, or via decarboxylation, supply plant nutrients and have organic compounds that could potentially move deep into soil profiles.

Experimental design

Two soils were collected from 10-20 cm soil layers: a Dermosol from Kinglake West, Victoria and a Sodosol from Holbrook, New South Wales. The Dermosol had pH of 4.1, pH buffer capacity (pHBC) of 86 mmol_c/kg/pH and extractable Al^{3+} of 12 µg/g. The Sodosol had pH of 3.9, pHBC of 23 mmol_c/kg/pH, extractable Al^{3+} of 1 µg/g and extractable Mn^{2+} of 70 µg/g.

Amendments used were: lime, dolomite, gypsum, KH2PO4, cow manure, sheep manure, poultry litter, dairy compost, immature hot mix compost, biosolids, brown coal, southern blue gum biochar, wheat straw biochar, poultry manure biochar, wheat straw, lucerne hay and kelp powder. All organic amendments were mixed with the soils at a rate of 1% soil weight. Lime and dolomite were applied to achieve a pH of 6, gypsum was applied equivalent to calcium added from lime and KH_2PO_4 was added at 338 mg/kg soil (3 times basal P).

Al-sensitive wheat, ES8, was grown for 7 weeks in a glasshouse experiment. ET8 (Al-tolerant wheat) was grown as a control to verify biological Al^{3+} toxicity as it is a isogenic pair of ES8 except for an Al^{3+}-activated malate transporter.

Figure 1. Wheat (Al-sensitive ES8) plants at harvest in a Sodosol and a Dermosol (49 days after sowing). Photo by Dominic Lauricella.

Results

- Poultry litter, poultry manure biochar (PM Biochar), dairy compost, biosolids and sheep manure consistently performed better across both soils.
- The different response between the soils is due to the Sodosol having a much lower pHBC and less Al^{3+} compared to the Dermosol (Sodosol had less ability to resist soil chemical changes).
- A variety of soil chemical changes were observed with most treatments decreasing $CaCl_{2-}$extractable Al and Mn.
- While pH change is generally a critical factor, soil pH was not significantly increased under most of treatments.
- The best organic amendments contained the highest concentrations of P and Olsen-P had a stronger relationship with shoot biomass responses than any other measured soil property.
- This slow release of P from amendments as they breakdown enables plants to take up more P by reducing the amount of P that is fixed by the acid soils.
- Poultry litter and poultry manure biochar showed very similar effects in ameliorating soil acidity, it is possible that the effects poultry manure biochar would persist much longer due to its greater ability to resist breakdown than an easily decomposable poultry litter.

Key messages

- On-farm plant-based amendments such as lucerne hay proved successful in significantly increasing plant biomass in the less hostile Sodosol.
- In the more hostile Dermosol, only high quality organic amendments such as manures with high concentrations of P increased crop biomass.
- Future research should identify organic amendments that not only have the ability to influence pH, Al3+ and Mn2+ toxicity, but also supply key plant nutrients to overcome the strong P-fixing capacity of acid soils.

Project partners and contacts

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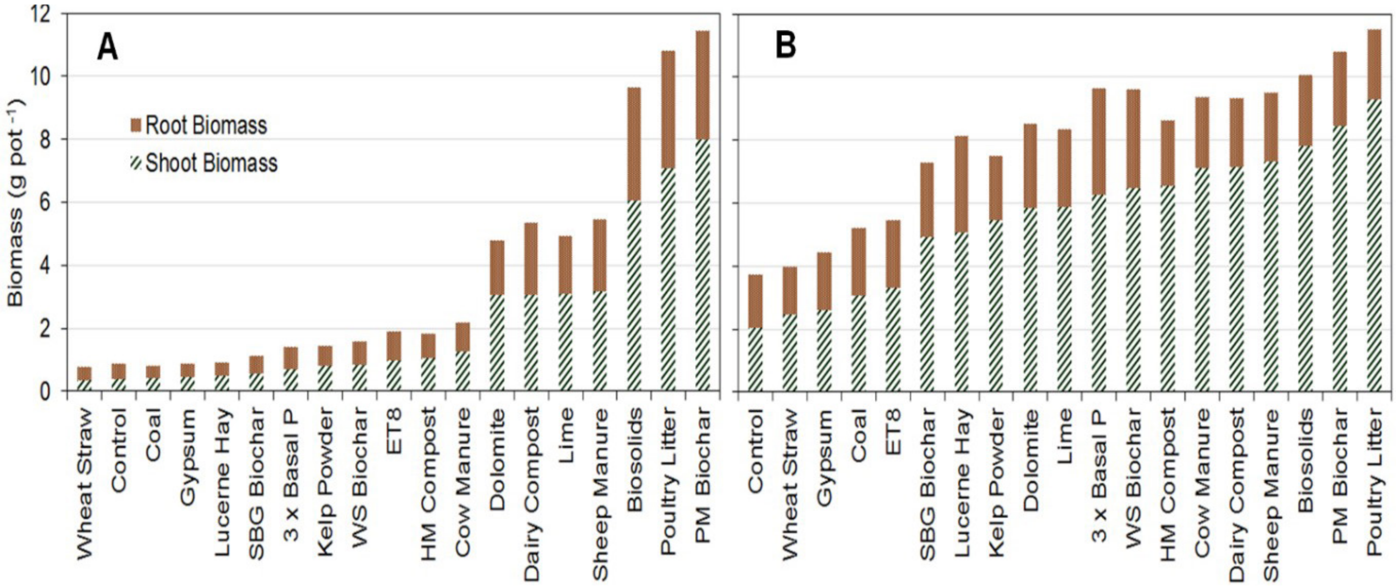

Figure 2. Effect of treatments on shoot and root biomass (g/pot) of Al-sensitive wheat ES8 grown in a Dermosol (A) and Sodosol (B) at 49 days after sowing. ET8 = Al-tolerant wheat, SBG = Southern blue gum, WS = Wheat straw, PM = Poultry manure, Basal P = 112.5 mg/kg KH2PO4, HM = Immature hot mix (n = 4).