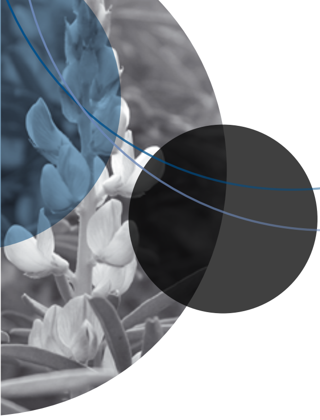

Nutrition & soils

Research update for the long-term subsoil acidity experiment at Cootamundra, NSW

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Key findings

- Deep placement of organic amendments (e.g. lucerne pellets) did not increase soil pH as high as measured in laboratory/glasshouse experiments, but it did reduce exchangeable aluminium (Al) significantly at 10–20 cm and 20–30 cm, indicating that the organic amendment would relieve Al toxicity by combining Al^{3+} to form insoluble compounds, hence reducing toxicity to plant growth.
- There was a large crop yield response to deep organic amendments in year 1 due to extra nutrients supplied from the lucerne pellets, but no crop response was detected in year 2, partly due to lack of soil moisture during the crop growing season. To date, soil treatments have had little effect on soil water.
- Soil chemical, physical and biological properties will continue to be monitored to understand the soil–plant interactions, the factors driving the differences in crop response to the various treatments, and the residual value of the amendments over the long-term.

Introduction

A long-term field experiment was set up in 2016 to run for at least two four-year crop rotation cycles, or one eight-year soil amendment cycle. The objectives were to:

1. manage subsoil acidity through innovative amelioration methods that will increase productivity, profitability and sustainability
2. study soil processes, such as the changes in soil chemical, physical and biological properties under vigorous soil amelioration techniques over the longer term.

Site details

Location	Dirnaseer, west of Cootamundra, NSW
Soil type	Red chromosol (Isbell 1996)
Previous crop	Oats
Crop rotation	Phase 1 EGA Gregory$^{\phi}$ wheat Phase 2 Hyola® 559TT canola Phase 3 La Trobe$^{\phi}$ barley Phase 4 Morgan$^{\phi}$ field pea (2016) PBA Samira$^{\phi}$ faba bean (2017)
Liming history	No lime for the past 10 years
Fallow rainfall	2016 (265 mm) (Nov–March) 2017 (302 mm) (Nov–March) Long-term average (261 mm Nov–March)

In-crop rainfall	2016 (676 mm) (April–Oct) 2017 (269 mm) (April–Oct) Long-term average (347 mm April–Oct)
Starter fertiliser	75 kg/ha di-ammonium phosphate (DAP) – 14% nitrogen (N), 15% phosphorus (P), 1% sulfur (S) for all crops
Top-dressing fertiliser	50–100 kg N/ha as urea for wheat, canola and barley, depending on the season
Ripping machine	3-D Ripper (5 tynes), designed and fabricated by NSW DPI
Ripping width and depth	50 cm between rip lines; to 30 cm depth

Crop rotation and treatments

There were four crops in rotation arranged in a fully phased design. The crops sequence is wheat (*Triticum aestivum*), canola (*Brassica napus*), barley (*Hordeum vulgare*), pulse, either faba bean (*Vicia faba*) or field peas (*Pisum sativum*) depending on the season. Each crop appears once in any given year so that:

1. responses of different crops to different soil amendments can be assessed
2. underlying treatment effects, taking account of seasonal variation, can be compared.

Table 1. Soil amendment and treatment description at Ferndale, west of Cootamundra, NSW.

ID	Treatment	Treatment description
1	No amendment	No amendment, representing the 'do nothing' approach.
2	Surface liming	Lime was applied at 4.0 t/ha, incorporated into 0–10 cm depth, to achieve an average pH_{Ca} of 5.5 over 8 years.
3	Deep ripping only	Soil was ripped down to 30 cm to quantify the physical effect of ripping. No amendment was applied below 10 cm, but lime was applied at 2.5 t/ha at the surface, incorporated into 0–10 cm depth after plots were ripped, to achieve an average pH_{Ca} of 5.0 over 8 years.
4	Deep liming	Lime was placed at three depths (surface, 10–20 cm and 20–30 cm). Approximately 5.5 t/ha of lime was applied in total to achieve a target pH >5.0 throughout the whole soil profile, which should eliminate pH restrictions to plant growth for most crops.
5	Deep organic amendment (OA)	Organic amendment (in the form of lucerne pellets) at 15 t/ha was placed at two depths (10–20 cm and 20–30 cm). The surface soil was limed to pH 5.0.
6	Deep liming plus OA	Treatments 4 and 5 were combined to maximise the benefits of lime and organic amendment.

Results

Soil chemical properties

There was no difference in soil pH at any depth in year 1 before treatments were imposed in 2016. In autumn 2017, one year after treatments were applied, surface liming increased pH to 5.9 at 0–10 cm. The deep liming treatment with and without OA significantly increased soil pH at 10–20 cm and 20–30 cm (Figure 1), showing the efficacy of the 3-D Ripper (Figure 2) to deliver soil ameliorants to depth (Li & Burns 2016).

However, the deep OA treatment did not increase pH as high as measured in laboratory/glasshouse experiments (data not shown). There are two possible explanations for this. First, the organic amendment was normally fully mixed with soil when it was incubated in the laboratory or put in soil columns in the glasshouse compared to that in the field where it was placed in a concentrated row in the rip line. Lack of homogenisation of the soil with OA makes it difficult to demonstrate what is more easily observed in a controlled environment with adequate water supply, usually maintained at field capacity. Secondly, all controlled environment experiments were conducted for 1–3 months, which would capture the initial soil pH increase due to decomposition of organic materials as demonstrated by Butterly et al (2010b). However, the subsequent nitrification processing would reduce soil pH (Butterly et al. 2010a). Nitrate leaching, if it occurs, will exacerbate the acidifying process. As a result, the net effect would keep soil pH unchanged in the longer term.

A number of soil column experiments demonstrated that the soluble component from organic material moves faster down the soil profile with alkali if combined with lime, compared with lime alone (Meda et al. 2002; Diehl et al. 2008). However, there is no evidence to show the lime being moved under lime plus OA in field conditions at this time. Monitoring soil pH will continue for the next few years to observe whether evidence of this emerges at the field site.

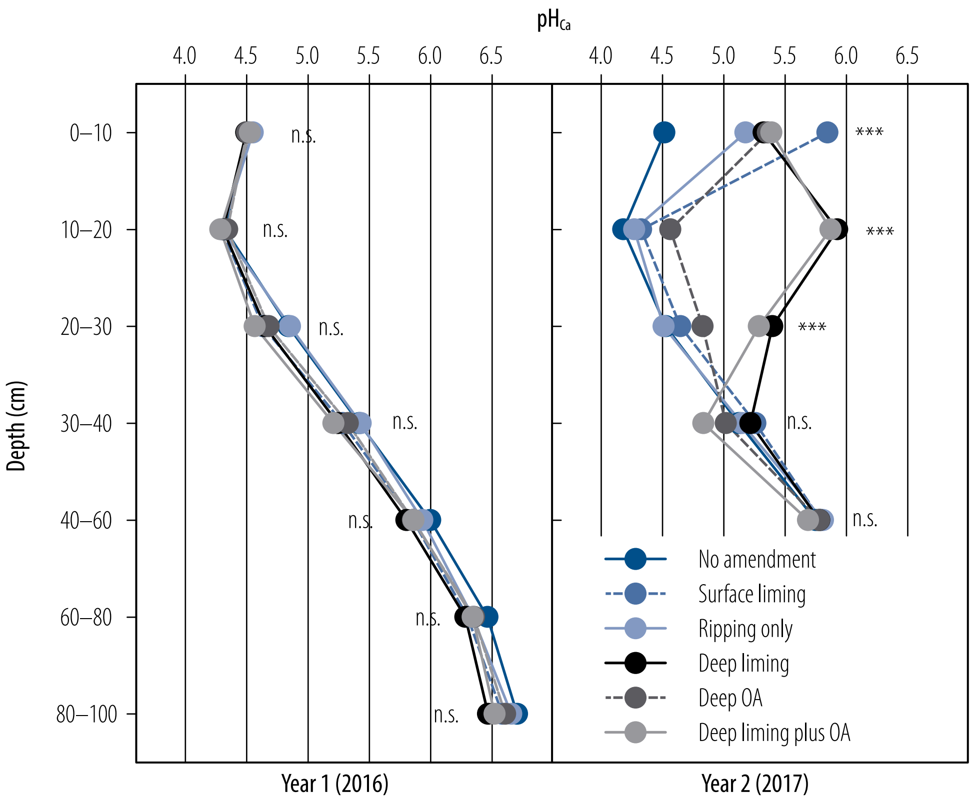

Figure 1. Soil pH_{Ca} under different soil amendment treatments in autumn in years 1–2 at the Cootamundra site; n.s., not significant.

Figure 2. 3-D Ripper, designed and fabricated by the NSW Department of Primary Industries.

Although OA did not increase soil pH, it did reduce exchangeable Al% significantly at 10–20 cm and 20–30 cm (Figure 3) compared with the no amendment treatment, indicating that the soluble organic molecules from OA could combine active Al^{3+} to form insoluble hydroxy-Al compounds (Haynes & Mokolobate 2001), which would reduce Al toxicity to plant growth.

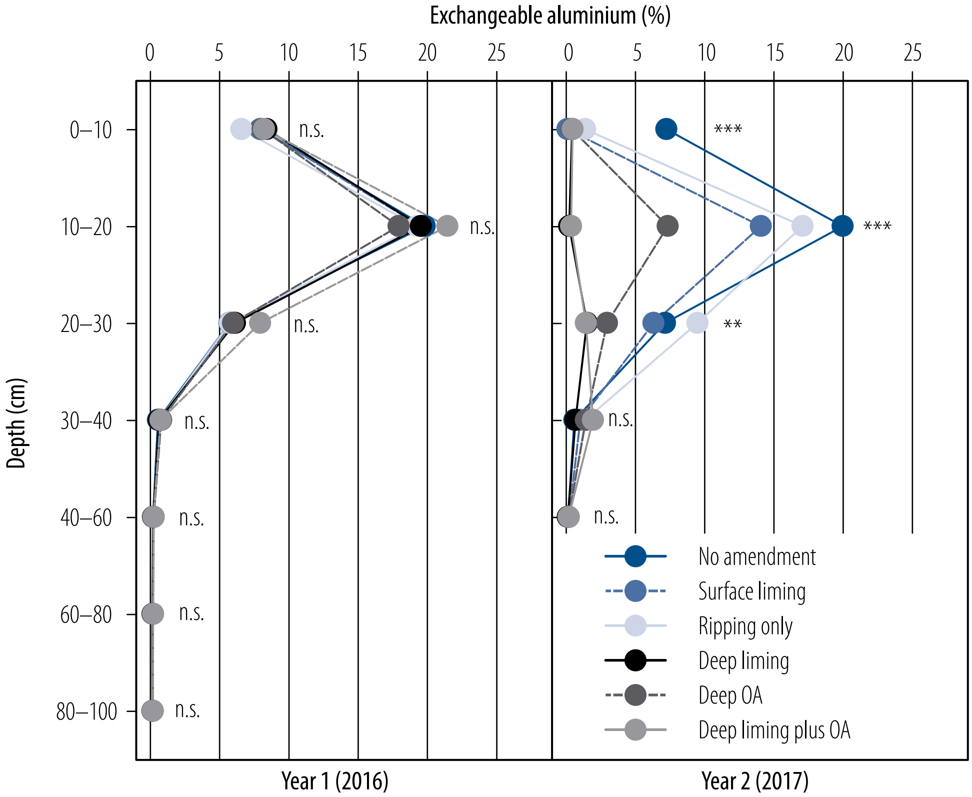

Figure 3. Soil exchangeable Al% under different soil amendment treatments in autumn in years 1–2 at the Cootamundra site; n.s., not significant.

There was significantly more soil mineral nitrogen (N) under the deep OA treatments with and without lime in spring 2016 (six months after treatments were implemented, $P<0.01$) and in autumn 2017 (12 months after treatments were implemented, $P<0.001$) (Figure 4), most likely due to the high N content (3.15%) of the lucerne pellets. On average, there was more than double the mineral N available on the deep OA and deep lime plus OA treatments compared with the remaining treatments.

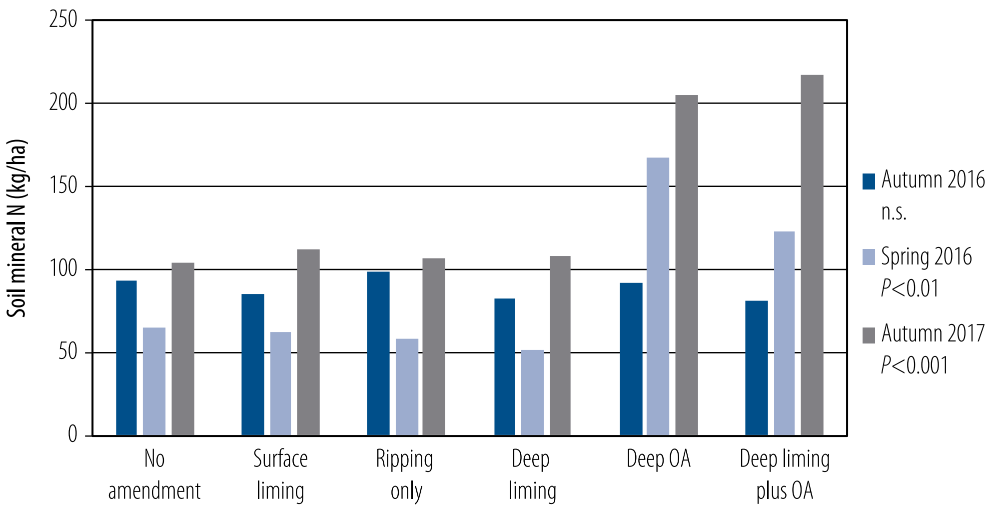

Figure 4. Soil mineral N (kg/ha) in 0–60 cm soil profile under different soil amendment treatments in autumn and spring in year 1, and autumn in year 2 at the Cootamundra site; n.s., not significant.

Rooting depth and root density

Rooting depth and root density was measured at crop anthesis at the end of October 2017 using the core-break method. Two soil cores were taken on each plot, one on the ripping line and the other between ripping lines. Data are presented on the average of two cores for each plot as no significant difference was found between two locations.

Canola was the deepest rooting crop, down to 140 cm and faba bean had the shallowest rooting depth (90–100 cm), whereas wheat and barley were intermediate. There was no significant difference in average maximum rooting depth between treatments (Figure 5).

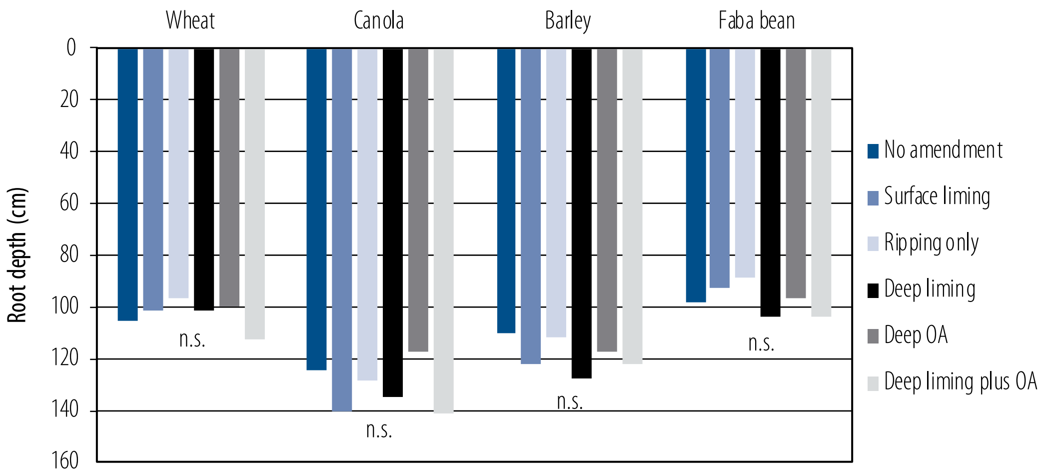

Figure 5. Maximum rooting depth (cm) under different soil amendment treatments at crop anthesis in year 2 at the Cootamundra site; n.s., not significant.

Soil total water

Neutron probe access tubes were inserted in autumn each year immediately after crops were sown then monitored for 12 months before new crops were sown in autumn the following year. One access tube was inserted between two ripping lines on each plot. Measurements were taken at six depths every 25 cm from 15 cm below soil surface down to 140 cm at 4–6 week intervals. The neutron probe reading was calibrated twice a year at the wettest and driest periods and the soil volumetric moisture content and soil total water in the profile were calculated.

The amount of soil water, in general, followed the rainfall pattern. In year 1, the soil profile was nearly full under all crops at the end of October due to the significant rainfall events. The site receiving 667 mm rainfall from May to October in that year. Late in the growing season, soil water decreased sharply for all crops due to high evapo-transpiration rates during the grain fill period. There was more soil water under the field pea crop at the end of November due to its earlier maturity and shallower rooting depth (Figure 6). The autumn and winter of year 2 were very dry and soil water remained at a constant level until the end of August before crop growth took off and water demands increased. During spring, soil water decreased to the lowest level due to vigorous crop growth and limited rainfall during that period among all treatments. The early summer rainfall re-filled the soil profile to different levels depending on soil moisture status in spring for different crops and treatments (Figure 6).

For wheat and canola in year 1, crops on treatments with deep soil amendments had lower soil water at the end of November 2016, particularly for the deep liming plus OA treatment (figures 6a and b) due to vigorous crop growth (Figure 8). In year 2, the deep liming treatment had the lowest soil water on the canola crop following the wheat crop (Figure 6a), whereas the deep liming plus OA treatment had lowest soil water on the barley crop following canola for the whole season (Figure 6b).

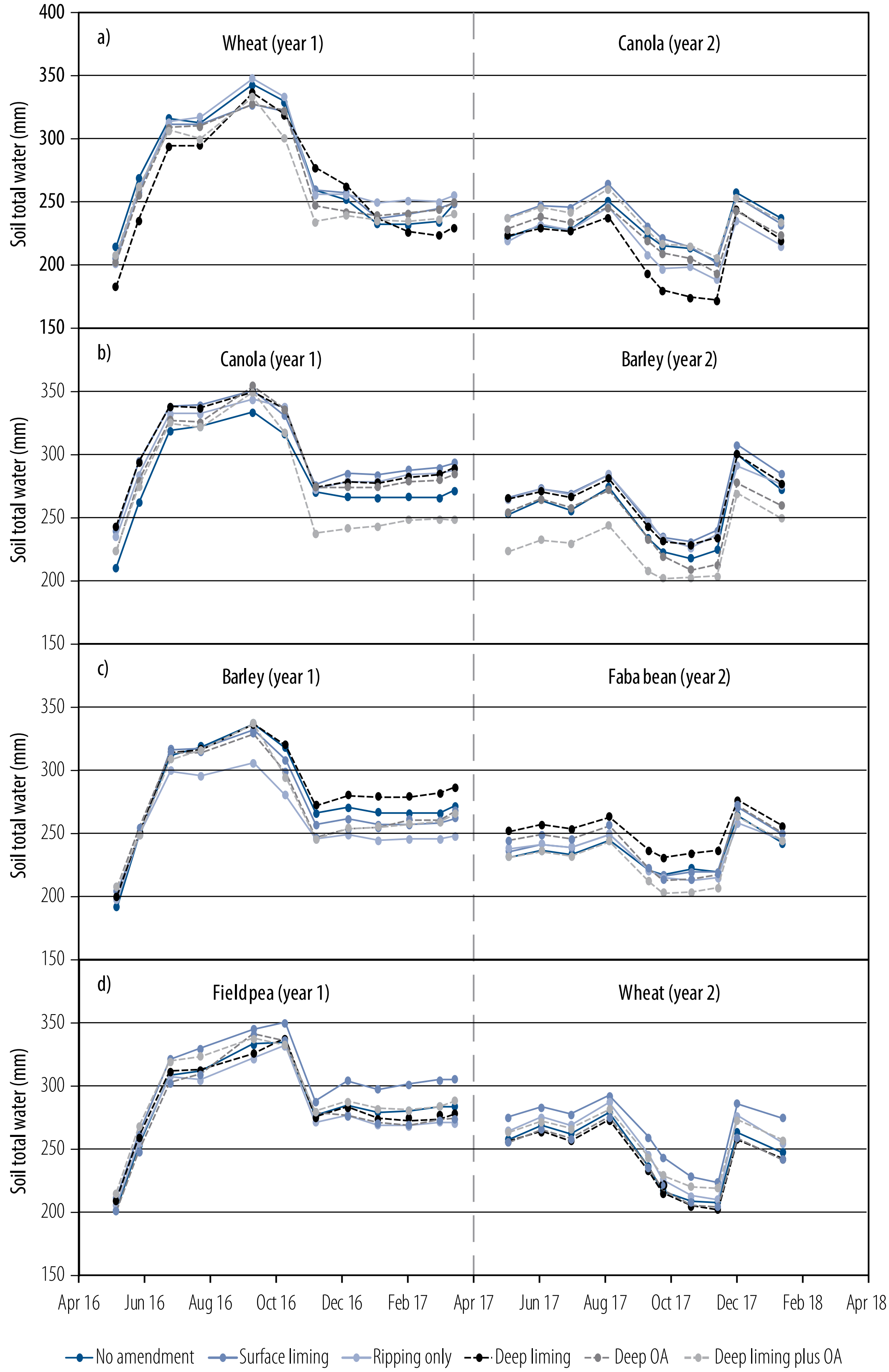

Figure 6. Soil water (mm) in the profile under different soil amendment treatments over two growing seasons (2016 and 2017) at the Cootamundra site.

For the barley crop in year 1, the ripping only treatment had the lowest soil water among all treatments during the early growing season, possibly due to more evaporation (Figure 6c). Later in the growing season during November, soil water on deep liming plus OA decreased sharply, reflecting the vigorous crop growth. Soil water on the deep liming treatment, however, was much higher than other treatments. In year 2, it was a very poor faba bean crop. Soil water on different treatments remained similar through the season with the highest soil water on the deep liming treatment and the lowest on the deep liming plus OA treatment.

For the field pea crop in year 1, there was not much difference in soil water during the growing season (Figure 6d); soil water was higher on this crop than other crops in year 1. The surface lime treatment had the highest soil water among all treatments after the crop was harvested. In year 2, vigorous wheat crops used more soil water and brought soil water down to a level similar to the other crops in the rotations (Figure 6d). Overall, soil amendment had little apparent effect on soil water values.

Agronomic performance

There was no significant difference in seedling density for all crops except for the barley crop where two treatments with deep OA had a higher seedling density in year 1 (Figure 7). There was no treatment difference in seedling density for any crops in year 2 due to the extremely dry conditions during crop establishment. The site only received 3.2 mm in June.

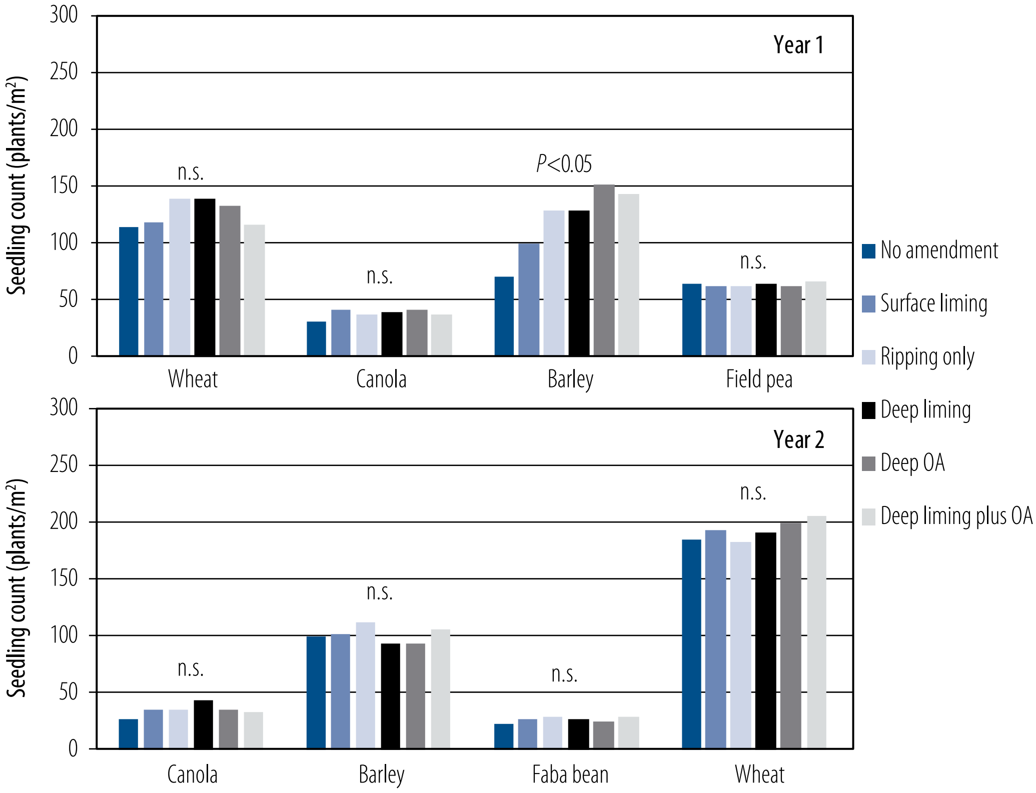

Figure 7. Seedling density (plants/m^2) at crop establishment in response to different soil amendments in years 1–2 at the Cootamundra site; n.s., not significant.

At anthesis, significant crop biomass responses were observed on wheat, barley and canola crops (Figure 8). The large crop biomass responses in year 1 under treatments with organic amendments applied were largely due to extra nutrients supplied by lucerne pellets (Figure 4). The dramatic crop biomass responses observed at anthesis on canola and barley crops did not translate into grain yield under treatments with lucerne pellets (Figure 9) due to severe lodging. In 2017, no significant difference was found for anthesis dry matter and grain yield between treatments for all crops (Figure 8). However, both deep OA and deep lime plus OA treatments tended to have a lower grain yield despite significantly higher mineral N at sowing (Figure 4). Lack of rainfall early in the growing season in 2017 (3.2 mm in September) and severe frost damage in late winter almost wiped out the canola and faba bean crops and severely suppressed the barley and wheat crops. The later growing season rainfall (53 mm and 70 mm in October and November, respectively) certainly boosted cereal crop grain yield (Figure 9).

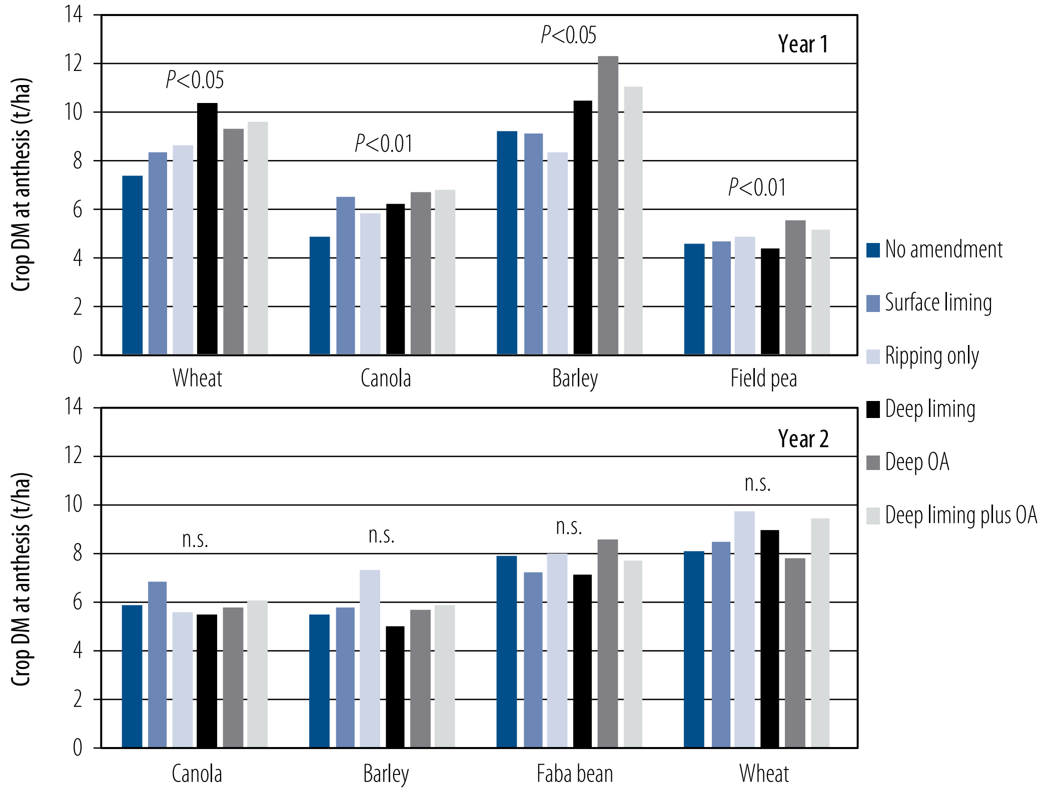

Figure 8. Crop dry matter (DM) at anthesis (t/ha) in response to different soil amendments in years 1–2 at the Cootamundra site; n.s., not significant.

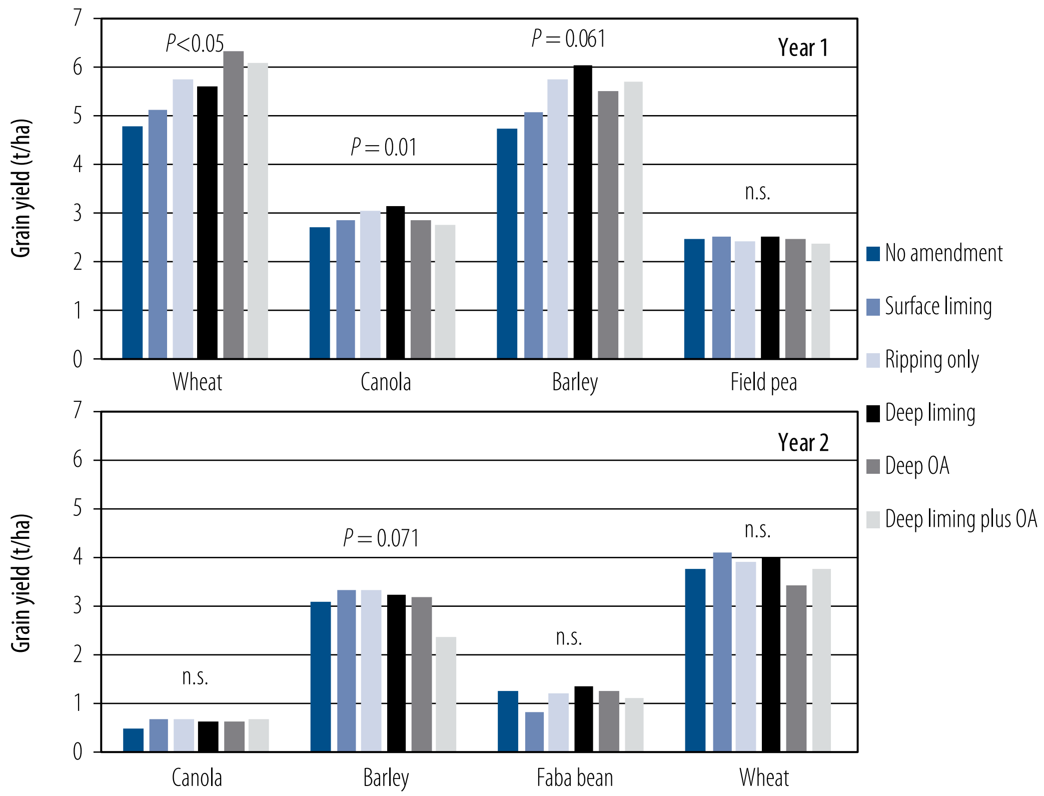

Figure 9. Grain yield (t/ha) in response to different soil amendments in years 1–2 at the Cootamundra site; n.s., not significant.

Conclusion

Deep placement of organic amendments (lucerne pellets) did not increase soil pH as much as that measured in laboratory experiments, but it did reduce exchangeable Al% significantly at 10–20 cm and 20–30 cm depth, indicating that the organic amendment would relieve Al toxicity by combining Al^{3+} to form insoluble compounds, hence reducing toxicity to plant growth.

There were large crop yield responses to deep organic amendment in year 1 due to extra nutrients supplied from the organic amendment, but no crop response was detected in year 2, partly due to a lack of soil moisture during the crop growing season. To date, soil treatments have had little effect on soil water.

Soil chemical, physical and biological properties will continue to be monitored to understand the soil–plant interactions, the factors driving the differences in crop response to the various treatments, and the residual value of the amendments over the long-term.

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