Research update for the long-term subsoil acidity experiment (2016–2019)

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Key findings

- Lime is the most effective amendment to increase pH and reduce exchangeable aluminium (Al).
- Deep placement of organic materials had a limited effect on soil pH, but reduced exchangeable aluminium percentage (Al%) significantly.
- The combination of lime with organic materials could facilitate alkalinity downwards in the soil profile in the short term.
- However, applying a large amount of organic materials could acidify soil over a longer term due to nitrification.
- No crop response was observed over the past three years due to severe drought conditions.

Introduction

Subsoil acidity is a major constraint to ongoing productivity in the high rainfall zone (500–800 mm) of south-eastern Australia (Scott et al., 2000). Approximately 50% of Australia's agriculture zone (~50 M ha) has a surface soil pH <5.5 in calcium chloride (pH_{Ca}, hereafter) and half of this area also has subsoil acidity (SoE, 2011). In southern NSW, there are 13.5 M ha of agricultural soils exhibiting a subsurface soil acidity problem (Dolling et al., 2001). The agricultural production loss from soil acidity was estimated as $387 million a year in NSW alone (SoE, 2011).

Applying lime to the surface is a widely accepted practice to combat soil acidification in top soils (Scott et al., 2000; Ryan, 2018). However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after decades of regular lime application where soil surface pH_{Ca} is maintained above 5.5 (Li et al., 2019). Results from two soil surveys conducted in 2006 and in 2015–2017 in southern NSW showed that soil acidity is continuing to move further down the soil profile even where lime was applied regularly over a 10 year period (Burns and Norton, 2018). The challenge, therefore, is how to stop further soil acidification and speed up the amelioration process in the subsoil.

To address the problem of subsoil acidification, a long-term field experiment was established in 2016. The objectives were to:

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

Site details

Location	Dirnaseer, west of Cootamundra, NSW
Soil type	Red chromosol (Isbell, 1996)

This research paper is an extract from the publication *Southern NSW Research Results 2020*, available at https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/southern-nsw-research-results

Crop rotation	Phase 1 Phase 2 Phase 3 Phase 4	EGA Gregory(ф) wheat Hyola® 559TT canola La Trobe(ф) barley Morgan(ф) field pea (2016, 2018) PBA Samira(ф) faba bean (2017, 2019)
Rainfall	See Table 1	
Starter fertiliser	14 kg nitrogen (N)/ha, 15 kg phosphorus (P)/ha and 1 kg sulfur (S)/ha as di-ammonium phosphate (DAP, 18% N, 20% P and 1.6% S) for all crops	
Top-dressing fertiliser	See Table 2	

Table 1 Fallow (November–March) and in-crop (April–October) rainfall in experiment years and long-term averages at Dirnaseer, west of Cootamundra, NSW.

Year	Fallow rainfall (mm)	In-crop rainfall (mm)
2016	265	682
2017	302	269
2018	244	173
2019	230	189
Long-term average	257	332

Table 2 Top-dressing fertiliser applied to crops at Dirnaseer, west of Cootamundra, NSW.

Crop	Top-dressing fertiliser
Canola and barley	86 kg N/ha as urea, total N fertiliser input 100 kg N/ha.
Wheat	36 kg N/ha as urea, total N fertiliser input 50 kg N/ha. It was assumed the previous grain legumes fixed at least 50 kg N/ha, thus total N input from fertiliser and biological fixation was equivalent to about 100 kg N/ha or above.
Pulse	No additional N fertiliser input apart from 14 kg N/ha as DAP at sowing.

Treatments

Experiment treatments are described in Table 3.

Table 3 Soil amendment and treatment description at Dirnaseer, west of Cootamundra, NSW.

ID	Treatment	Treatment description
1	Nil amendment	No amendment, representing the 'do nothing' approach.
2	Surface liming	Lime was applied at 4.0 t/ha, incorporated to 10 cm deep, calculated to achieve an average pH_{Ca} >5.5.
3	Deep ripping only	Soil was ripped to 30 cm deep with no amendment. However, the surface soil was limed at 2.5 t/ha, incorporated to 10 cm deep, calculated to achieve an average pH_{Ca} of 5.0.
4	Deep liming	Lime was deep-placed in the 10–30 cm depth with ripping. Surface soil was also limed and incorporated to 10 cm, targeted to achieve an average pH_{Ca} of 5.0 at 0–30 cm. Total lime used was 5.5 t/ha.
5	Deep lucerne pellets (LP)	Deep organic amendment in the form of lucerne hay pellets (LP, 15 t/ha) was deep-placed at 10–30 cm deep. The surface soil was limed and incorporated to 10 cm, targeted to achieve an average pH_{Ca} of 5.0.
6	Deep liming plus LP	A combination of treatments 4 and 5, with lime and LP to maximise the benefits of lime and organic materials.

Measurements

Soil chemical analysis

Soil pH_{Ca}, exchangeable cations, soil mineral N.

Rooting depth and root density

Maximum rooting depth and root density for each crop at anthesis.

Crop agronomy

Seedling count at establishment, crop dry matter (DM) at anthesis and grain yield.

Results and discussion

Soil chemical properties

Deep liming and deep liming with LP significantly increased soil pH at 10–20 cm and 20–30 cm in 2017, 12 months after treatments were implemented. During 2018 and 2019, soil pH was maintained at ~6.0 at 10–20 cm for both deep liming and deep liming with LP treatments. However, by 2019 soil pH at 20–30 cm reduced to levels similar to the nil control on both deep liming and deep liming with LP treatments (Figure 1). This is most likely due to nitrification of organic materials and mineral N plant uptake that produced an excess of hydrogen ions. Soil pH for the surface liming treatment was maintained above 5.5, but had no effect on subsoil pH over 2017 to 2019.

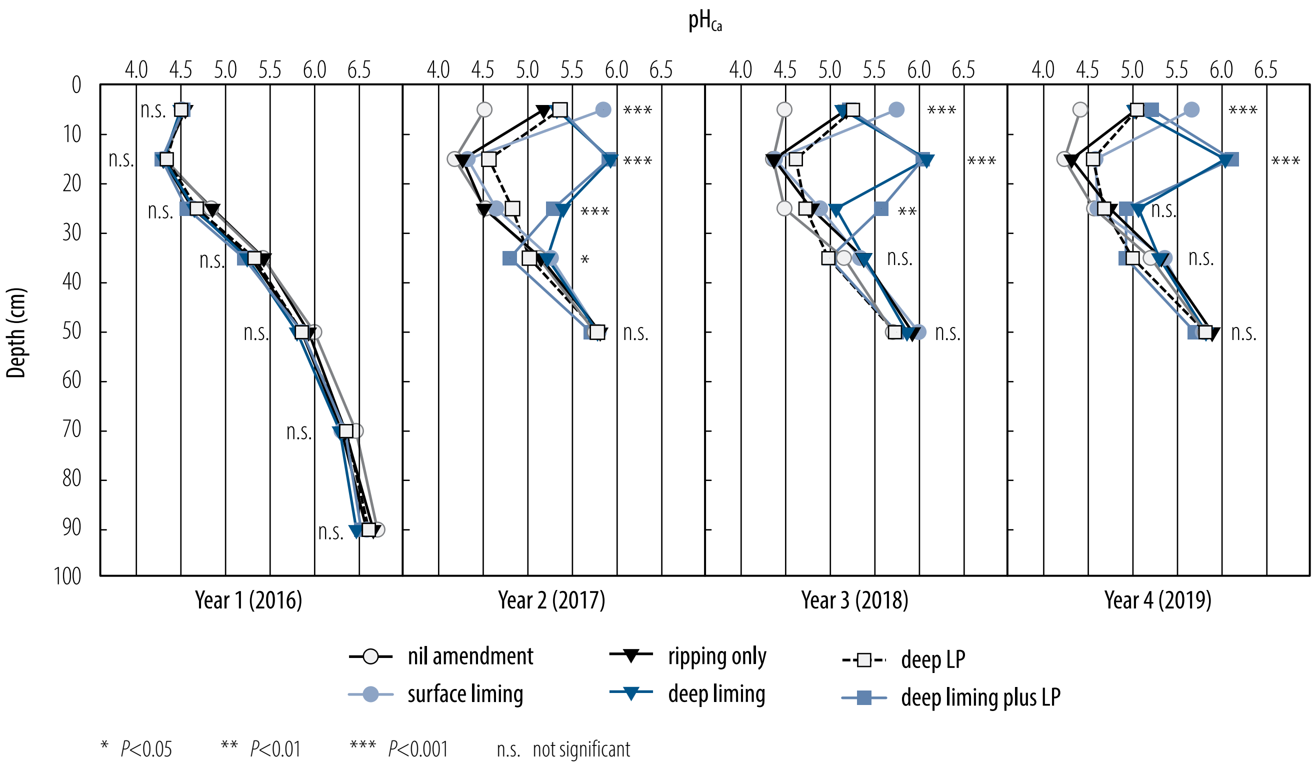

Figure 1 Soil pH (pH_{Ca}) under different soil amendment treatments in autumn in years 1–4.

Decomposed organic materials are known to increase soil pH initially (Butterly et al., 2010b), then reduce the soil pH subsequently due to the nitrification process (Butterly et al., 2010a). When combined with lime, the soluble component from organic materials moved down the soil profile with the alkali (Nguyen et al., 2018), hence ameliorating subsoil acidity. However, results from this experiment showed that pH below the depth of soil amendments (>30 cm) decreased slightly over three years under the LP treatments with and without lime. This indicated that applying a large amount of organic material could acidify the soil in the field over the long term (Figure 2). Further research is required to confirm this finding in the field.

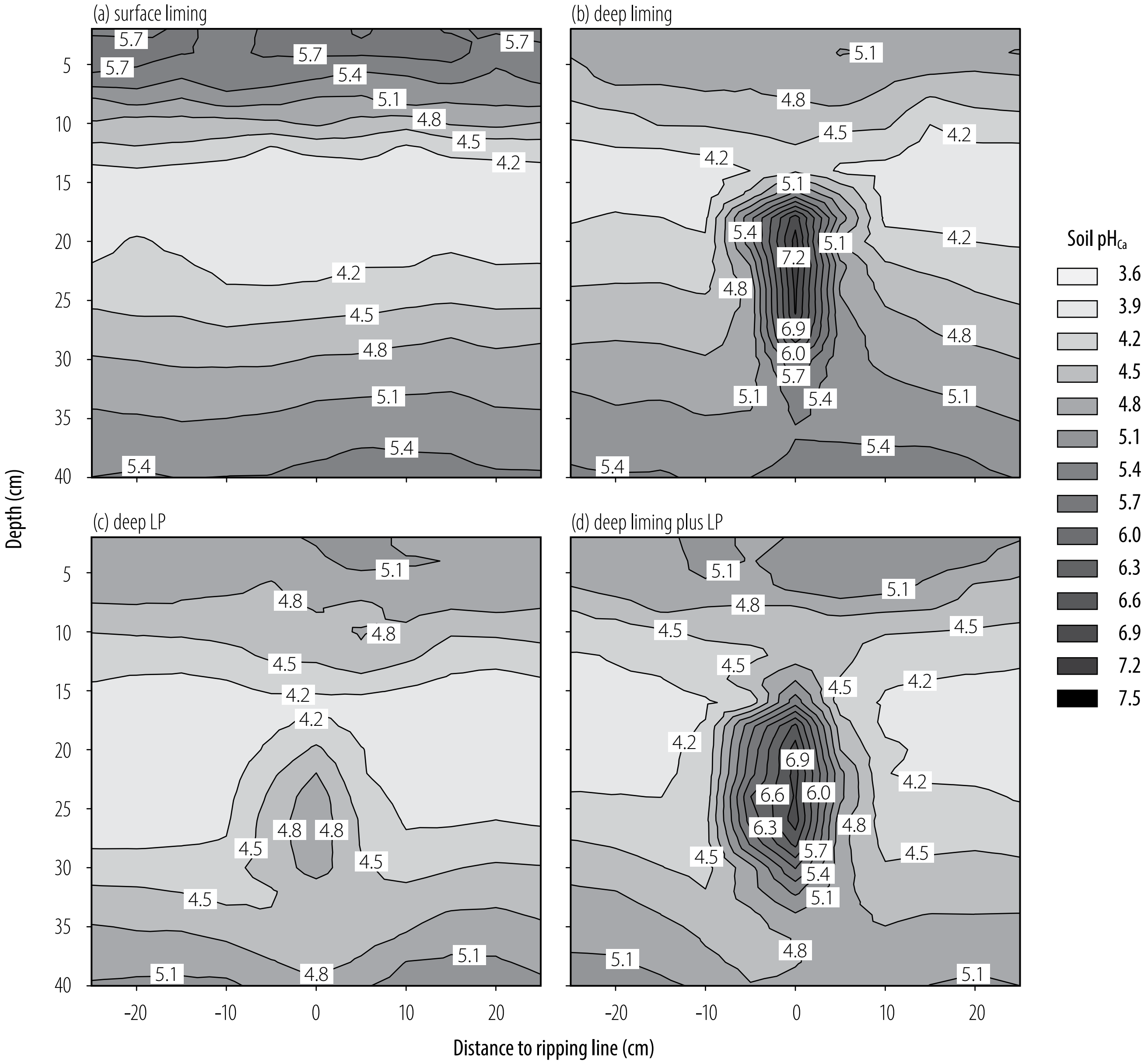

Figure 2 The spatial distribution of soil pH (pH$_{Ca}$) in the soil profile with (a) surface liming, (b) deep liming, (c) deep LP, and (d) deep liming plus LP in 2019, four years after treatments were implemented.

Deep liming with and without LP significantly reduced exchangeable Al% at 10–30 cm one year after treatments were implemented (Figure 3). The exchangeable Al level was maintained below 3% through to 2019.

Although LP did not increase soil pH as much as expected, it did reduce exchangeable Al% significantly at 10–20 cm, compared with the nil treatment. At 20–30 cm, the treatment difference was significant for exchangeable Al% in 2017 and 2018, but not in 2019. It is possible that the soluble organic molecules from organic amendments combines with active Al^{3+} to form insoluble hydroxy-Al compounds as suggested by Haynes and Mokolobate (2001).

There was significantly more soil mineral N at 0–60 cm under deep LP and deep liming with LP treatments in 2017–2019 (P<0.001) compared with treatments without LP (Figure 4). On average, there was an additional 100 kg N/ha soil mineral N available in deep LP and deep liming with LP treatments compared with all other treatments in 2017–2019 (Figure 4). This indicates that the nutrients derived from LP could last more than three years, which could have been prolonged by low nutrient removal over the drought-affected years of 2018 and 2019.

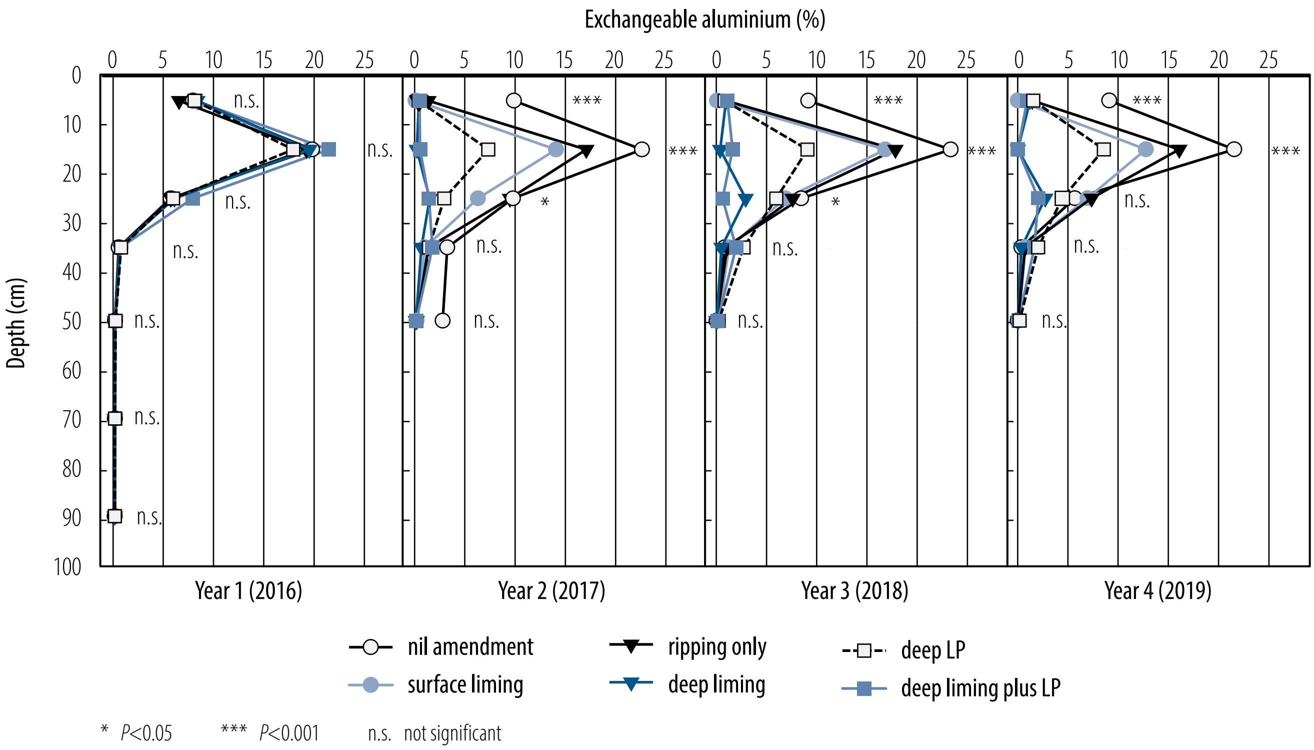

Figure 3 Soil exchangeable aluminium (%) under different soil amendment treatments in years 1–4.

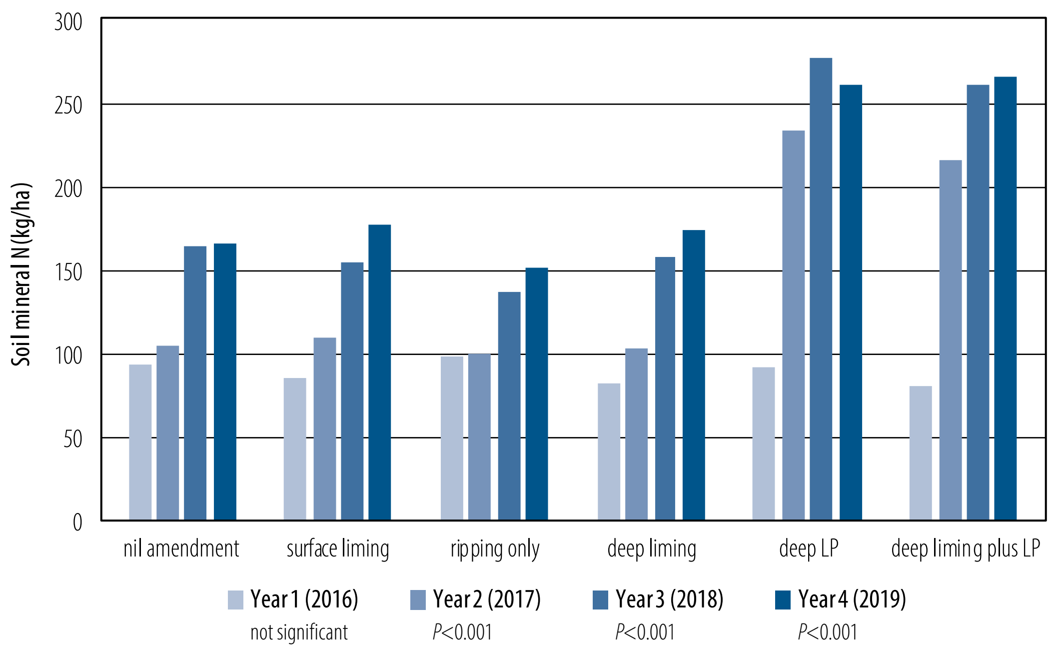

Figure 4 Soil mineral nitrogen (kg/ha) at 0–60 cm under different soil amendment treatments in autumn in years 1–4.

Rooting depth and root density

Averaged across crops and seasons, there was no significant difference in maximum rooting depth between treatments (Figure 5a). However, there were significant differences in maximum rooting depth between crops for most of the treatments (Figure 5b). Canola, in general, had the deepest roots, reaching down to 126 cm, and pulses (field pea or faba bean) had the shallowest rooting depth (100 cm). Wheat and barley rooting depths were intermediate. It was observed that rooting depth was shallower in a wet year (2016), but deeper in dry years (2018 and 2019), highlighting a key crop response to dry seasonal conditions.

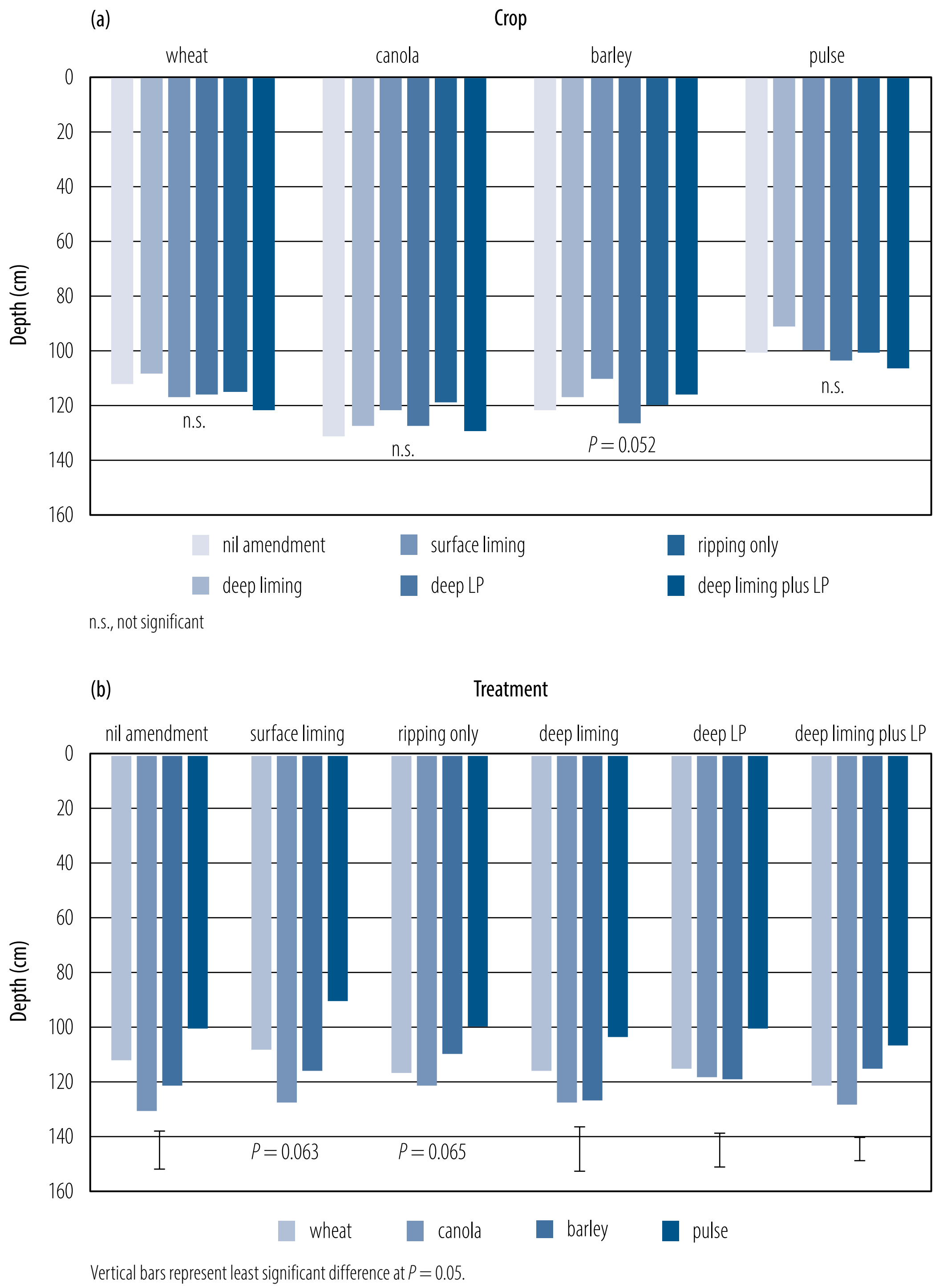

Figure 5 Maximum rooting depth (cm) for (a) each crop under different soil amendment treatments and (b) each treatment under different crops at crop anthesis in years 1–4 at the Cootamundra site.

Root density decreased with soil depth with the highest root density located at 0–10 cm depth, which was most evident in dry years. There were significant differences in root density between treatments at 10–20 cm and 20–30 cm depth where soil amendments were applied (Figure 6). The deep ripping treatments, particularly for those with soil amendments, tended to have more roots in these subsurface layers compared with nil and surface limed treatments. There was a tendency for the nil treatment and surface liming treatment to have higher root density compared with other treatments at 0–10 cm depth, particularly in the dry years.

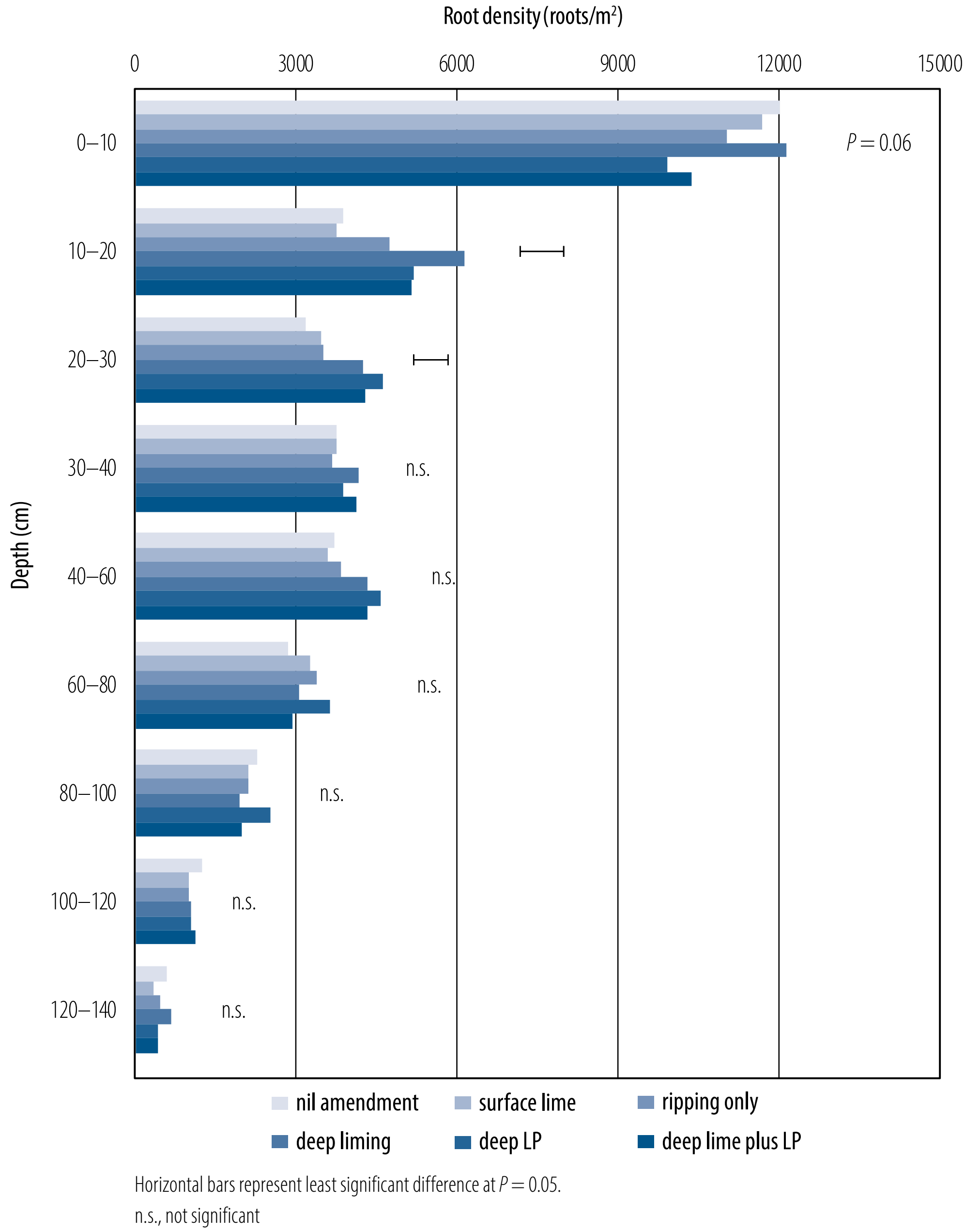

Figure 6 Averaged root density (roots/m^2) across crops in 2016–2019 under different soil amendment treatments at crop anthesis at the Cootamundra site.

Grain yield

In 2016, deep LP and deep liming with LP produced the highest grain yield for the wheat crop, but not in canola and barley crops. The wheat crop response on the treatments with LP was due to additional N supplied via LP decomposition in these treatments. The lack of response in canola and barley crops was due to severe lodging late in the growing season. There was no difference in grain yield between treatments for field pea in 2016 (Figure 7). There was no significant difference in grain yield for any crops in 2017–2019. This could have been due to the severe drought conditions, which limited potential yields. The site only received 269 mm, 173 mm and 189 mm of in-crop rainfall over 2017–2019, compared to a long-term average growing season rainfall of 332 mm. Canola yielded less than 1.0 t/ha of grain in 2017–2018 years and about 200 kg/ha in 2019. Faba bean yielded approximately 1.0 t/ha of grain in 2017 and less than 350 kg/ha in 2019, while field pea yielded less than 800 kg/ha in 2018.

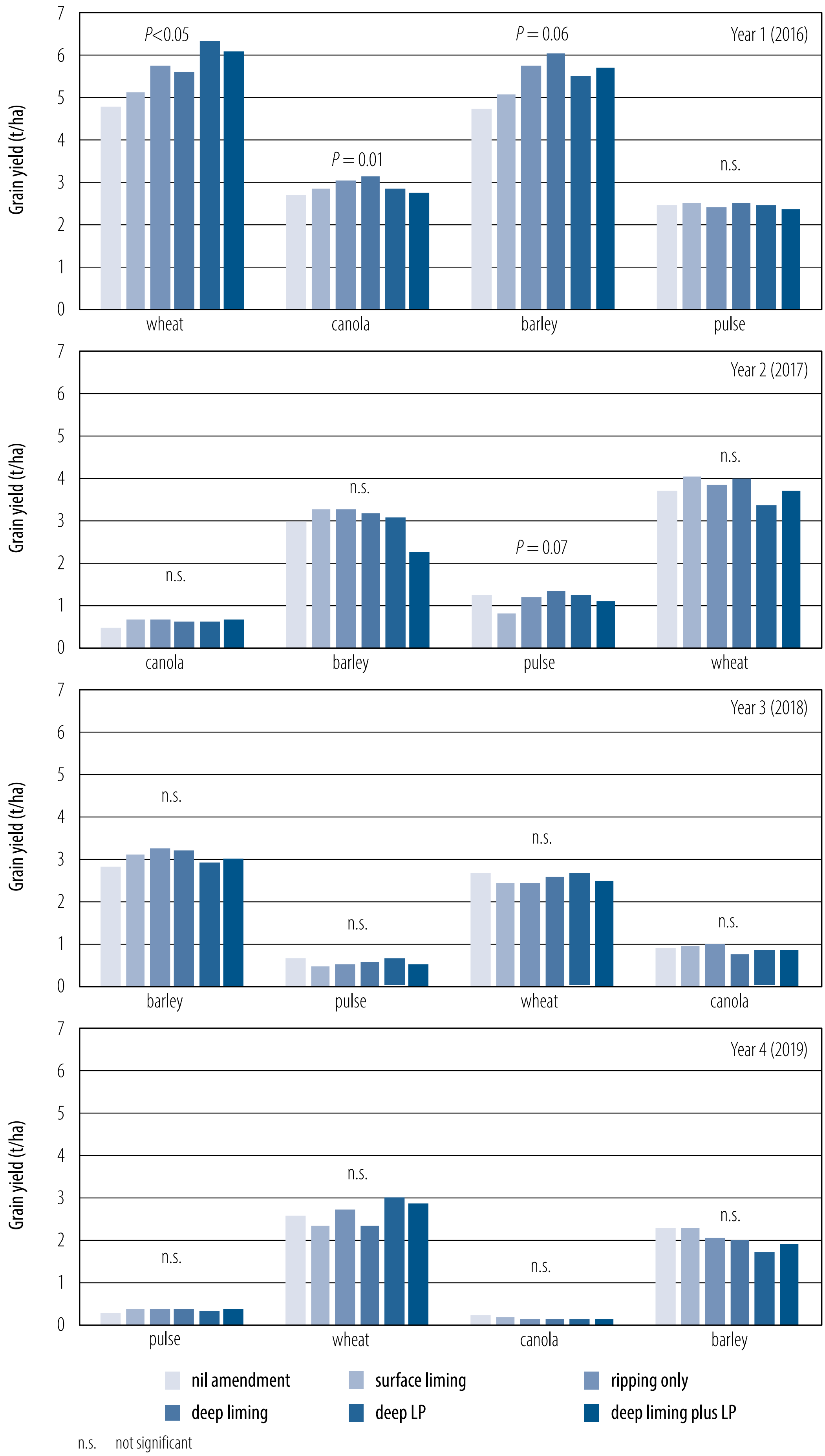

Figure 7 Grain yield (t/ha) in response to different soil amendments in years 1–4.

Conclusions

Lime is the most effective amendment to increase pH and reduce exchangeable Al%. Deep placement of organic materials had a limited effect on soil pH, but significantly reduced the exchangeable Al. However, in the longer term, applying large amounts of organic materials could acidify soils through nitrification and this would need to be offset with additional lime to neutralise this effect.

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Acknowledgements

The project is a NSW Department of Primary Industries investment, with financial support from GRDC.

Thanks to Richard Lowrie, Adam Lowrie, Andrew Price, Albert Oates, Yan Jia and Alek Zander for their quality technical support, and to Tony Flanery, the leasee, and Ian Friend, the landowner of Ferndale, Dirnaseer, NSW for their ongoing cooperation since 2016.