Department of Primary Industries
Department of Regional NSW

# NSW research results

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

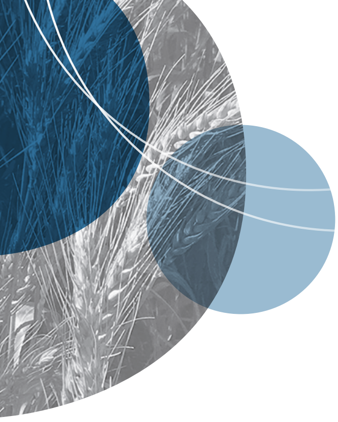
The following paper is from an edition of the Northern or Southern New South Wales research results book.

Published annually since 2012, these books contain a collection of papers that provide an insight into selected research and development activities undertaken by NSW DPI in northern and southern NSW.

Not all papers will be accessible to readers with limited vision.
For help, please contact: Carey Martin at carey.martin@dpi.nsw.gov.au



Published by NSW Department of Primary Industries,
a part of the Department of Regional New South Wales.



# Nutrition & soils

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

Dr Guangdi Li[1,3], Richard Hayes[1,3], Dr Jason Condon[1,2,3], Dr Sergio Moroni[2,3], Dr Ehsan Tavakkoli[1,3], Helen Burns[1], Richard Lowrie[1], Adam Lowrie[1], Graeme Poile[1], Albert Oates[1], Andrew Price[1] and Alek Zander[2]

[1] NSW Department of Primary Industries, Pine Gully Road, Wagga Wagga, NSW 2650

[2] Charles Sturt University, Boorooma Street, Wagga Wagga, NSW 2650

[3] Graham Centre for Agricultural Innovation, Albert Pugsley Place, Wagga Wagga, NSW 2650

### Key findings

- Lime is the most effective amendment to increase pH and reduce exchangeable aluminium (Al).
- Deep placement of organic amendments (e.g. lucerne hay pellets) had limited effect on soil pH, but reduced exchangeable Al% significantly.
- The nutrients in lucerne hay pellets, particularly nitrogen (N), increased soil mineral N significantly, but its effectiveness depends on available soil water. In dry years, there was no yield improvement, despite more soil mineral N being available at sowing.
- In dry years, crops developed more roots at 0–10 cm, presumably to capture valuable rainfall, rather than producing deeper roots to seek non-existent soil moisture. However, in a wet year (i.e. 2016), root systems were distributed more evenly in the soil profile.
- There was no crop response in grain yield in 2017 and 2018 due to lack of soil moisture. The available soil water was in deficit for much of the soil profile during most of the growing season in 2017 and 2018 for canola and cereal crops.
- Grain protein was higher under the deep lucerne hay pellet treatments, with and without lime addition, compared with other treatments, in both wet and dry years.

### Introduction

A long-term field experiment was established in 2016 to manage soil acidity at depths of 10–30 cm. The objectives were to:

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

### Site details

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

| | | |
|---|---|---|
| **Previous crop** | Oats | |
| **Crop rotation** | Phase 1 | EGA Gregory⍭ wheat |
| | Phase 2 | Hyola® 559TT canola |
| | Phase 3 | La Trobe⍭ barley |
| | Phase 4 | Morgan⍭ field pea (2016) |
| | | PBA Samira⍭ faba bean (2017) |
| | | Morgan⍭ field pea (2018) |
| **Liming history** | No lime applied in the previous 10 years | |
| **Fallow rainfall (November–March)** | 2016 (265 mm); 2017 (302 mm); 2018 (244 mm); long-term average (257 mm) | |
| **In-crop rainfall (April–October)** | 2016 (682 mm); 2017 (269 mm); 2018 (173 mm); long-term average (332 mm) | |
| **Starter fertiliser** | 14 kg 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** | Canola and barley: 86 kg N/ha as urea, total N fertiliser input 100 kg N/ha<br>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.<br>Grain legumes: no additional N fertiliser input apart from 14 kg N/ha as DAP at sowing. | |
| **Ripping machine** | 3-D Ripper (5 tynes), designed and fabricated by NSW DPI (Li and Burns 2016) | |
| **Ripping width and depth** | 50 cm between rip lines; to 30 cm deep | |

## Crop rotation and treatments

There were four crops in rotation arranged in a fully-phased design. The crop sequence was wheat (*Triticum aestivum*), canola (*Brassica napus*), barley (*Hordeum vulgare*), pulse – either faba bean (*Vicia faba*) or field pea (*Pisum sativum*) depending on the season (field pea was sown in year one and year three, and faba bean was sown in year two). Each crop appeared once in any given year so that:

- responses of different crops to different soil amendments can be assessed
- 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 | Nil amendment | No amendment, representing the 'do nothing' approach. |
| 2 | Surface liming | Lime was applied at 4.0 t/ha, incorporated to 0–10 cm deep to achieve an average $pH_{Ca}$ of 5.5 over eight 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 to 0–10 cm deep after plots were ripped, to achieve an average $pH_{Ca}$ of 5.0 over eight 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 hay 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. |

## Measurements

Soil samples were taken in autumn at 10 cm increments from 0–40 cm, and 20 cm increments from 60–100 cm at phase 1, but only to 60 cm at remaining phases. Soil samples were analysed for pH, exchangeable cations, soil mineral N and Colwell P.

Rooting depth and root density were measured at crop anthesis in each year using breaking corer methods (Smit et al. 2000). Two soil cores were taken between crop rows on the ripping line and between ripping lines on each plot. Data was averaged across two cores on each plot as no significant difference between the two cores was found for any year.

Neutron probe access tubes were inserted in autumn each year for approximately 12 months immediately after crops were sown and removed within a week before new crops were sown in autumn in the following year. One access tube was inserted to a depth of 150 cm 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 site received 576 mm of rain from June to September in 2016; by 26 September the soil profile was nearing field capacity. Therefore, the soil moisture measured on 26 September 2016 was deemed as the crop drainage upper limit (DUL). Over three years, the lowest neutron moisture meter (NMM) count readings were recorded on 19 November 2018 for all depths except for the first depth at 15 cm where the lowest NMM count was on 9 October 2018. However, the soil moisture measured at 15 cm on 19 November 2018 was similar to the plant permanent wilting point at 1.5 kPa tension measured in the laboratory (0.08 g/cm$^3$). Therefore, the soil moisture measured on 19 November 2018 was deemed as the crop lower limit (CLL) for the calculation. The available soil water (ASW) was soil water stored at a given time less the CLL for given soil depths.

Seedling numbers at establishment, crop dry matter (DM) at anthesis and harvest, grain yield and quality were also measured.

## Results and discussion

### Rainfall pattern

At the Cootamundra site, the long-term annual rainfall is 589 mm. It was an extremely wet year in 2016 with 947 mm of rain when the experiment was set up. However, the following two years, 2017 and 2018, were extremely dry, particularly during the growing season. In 2017, the site only received 3.2 mm of rain in June and in September. In 2018, over four months from July to October, the site only received 16.5, 26.5, 25.9 and 21.2 mm of rain, respectively (Figure 1).

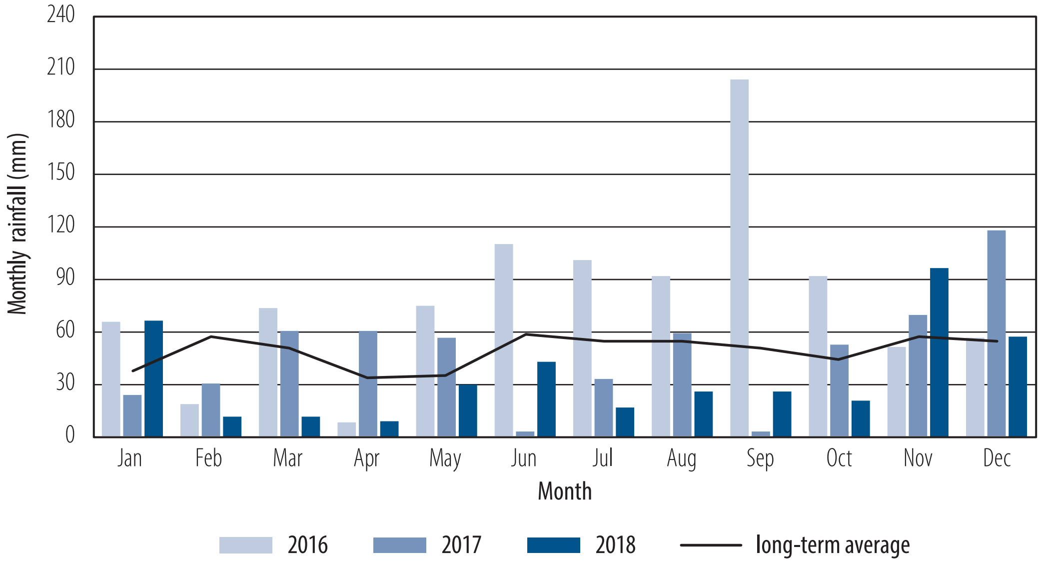



Figure 1. Monthly rainfall and long-term average rainfall at Cootamundra, NSW.

### Soil chemical properties

*Soil pH*

The baseline samples showed that soil pH was 4.52 at 0–10 cm deep, 4.31 at 10–20 cm and 4.70 at 20–30 cm. There was no difference in soil pH between treatments at any depth in year one before treatments were imposed. In autumn 2017, 12 months after treatments were imposed, surface liming increased pH to 5.9 at 0–10 cm as designed. The deep-lime treatment with and without organic amendment (OA) significantly increased soil pH at 10–20 cm and 20–30 cm as expected. Similar trends were found in 2018 (Figure 2).

The deep OA treatment did not increase pH to the level that pilot laboratory/glasshouse experiments suggested (unpublished data). There are several explanations for this unexpected result. Firstly, in the incubation or soil column experiments, the organic amendment was fully mixed with soil in contrast to the field experiment where it was banded at two depths after one pass with the 3D ripper. Secondly, there was adequate water supply in the controlled environment, maintained at 80% of field capacity, whereas in the field soil moisture was variable. In addition, nearly all controlled environment experiments were conducted over a comparatively short duration, up to three months.

It is reported that decomposed organic materials initially increased soil pH (Butterly et al. 2010b), however, the nitrification process decreased soil pH (Butterly et al. 2010a). The net effect would keep soil pH unchanged assuming that the magnitude of change cancel each other. A number of soil column experiments demonstrated that the soluble component from organic materials moves down the soil profile with the alkali if combined with lime (Butterly and Tang 2018; Nguyen et al. 2018). However, there is no evidence to show that the alkalinity moved vertically under lime plus organic amendment in the first three years of the current field experiment.

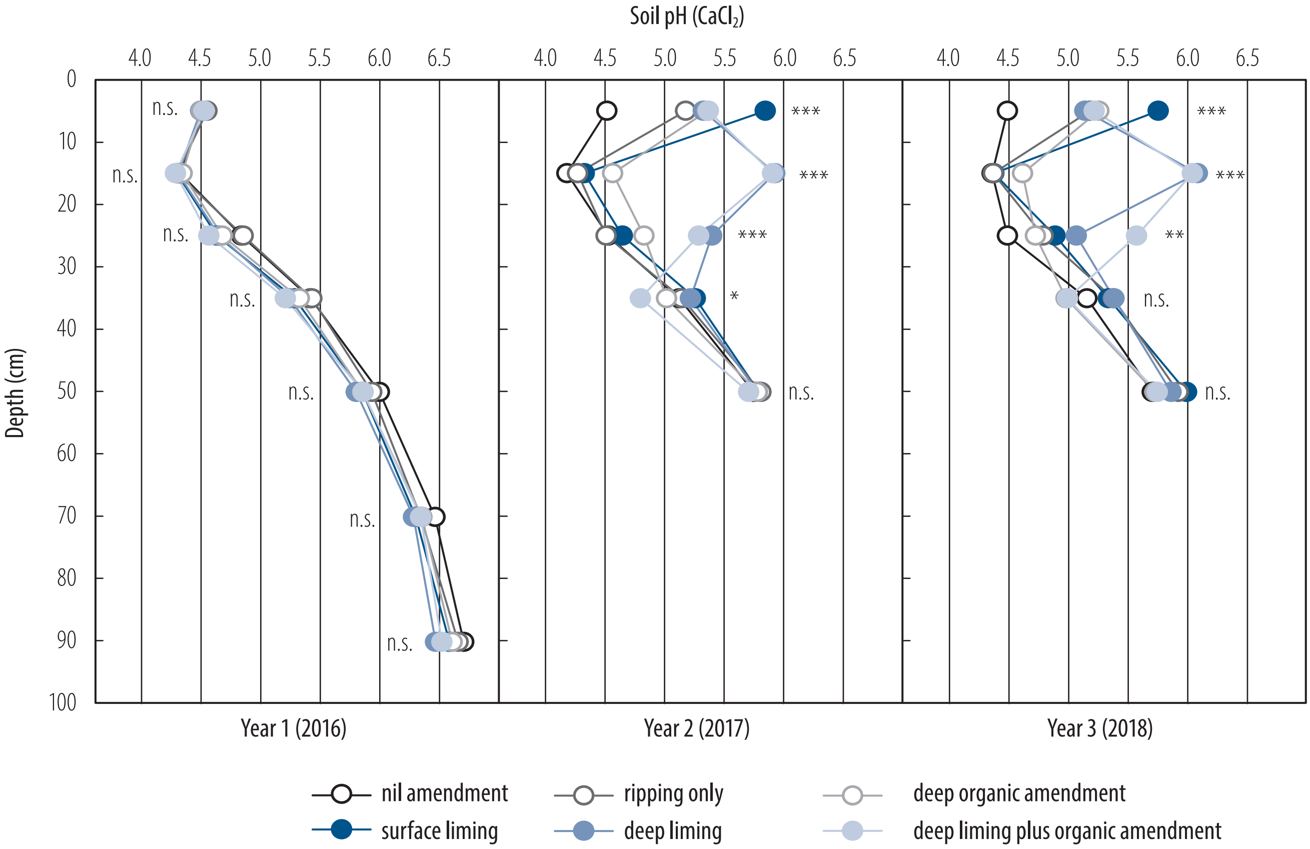



Figure 2. Soil pH in $CaCl_2$ under different soil amendment treatments in autumn in years 1–3.
**, P < 0.05; **, P < 0.01; ***, P < 0.001; n.s., not significant.*

### *Exchangeable aluminium (Al)*

Before imposing treatments in 2016, the baseline exchangeable Al was 19.6% and 6.2% at 10–20 cm and 20–30 cm, respectively. The deep-liming treatments, either with or without organic amendment, reduced exchangeable Al to less than 2% in 2017 and 3% in 2018 at 10–30 cm (Figure 3). Although the organic amendment did not increase soil pH, it did reduce exchangeable Al significantly at 10–30 cm compared with those treatments without deep soil amendment placement. Haynes and Mokolobate (2001) suggested that the soluble organic molecules from organic amendment could combine active $Al^{3+}$ to form insoluble hydroxy-Al compounds. The exchangeable Al remained high in the 10–30 cm depths for ripping only and surface liming treatments. The nil amendment treatment had the highest exchangeable Al at all three depths at 0–30 cm (Figure 3).

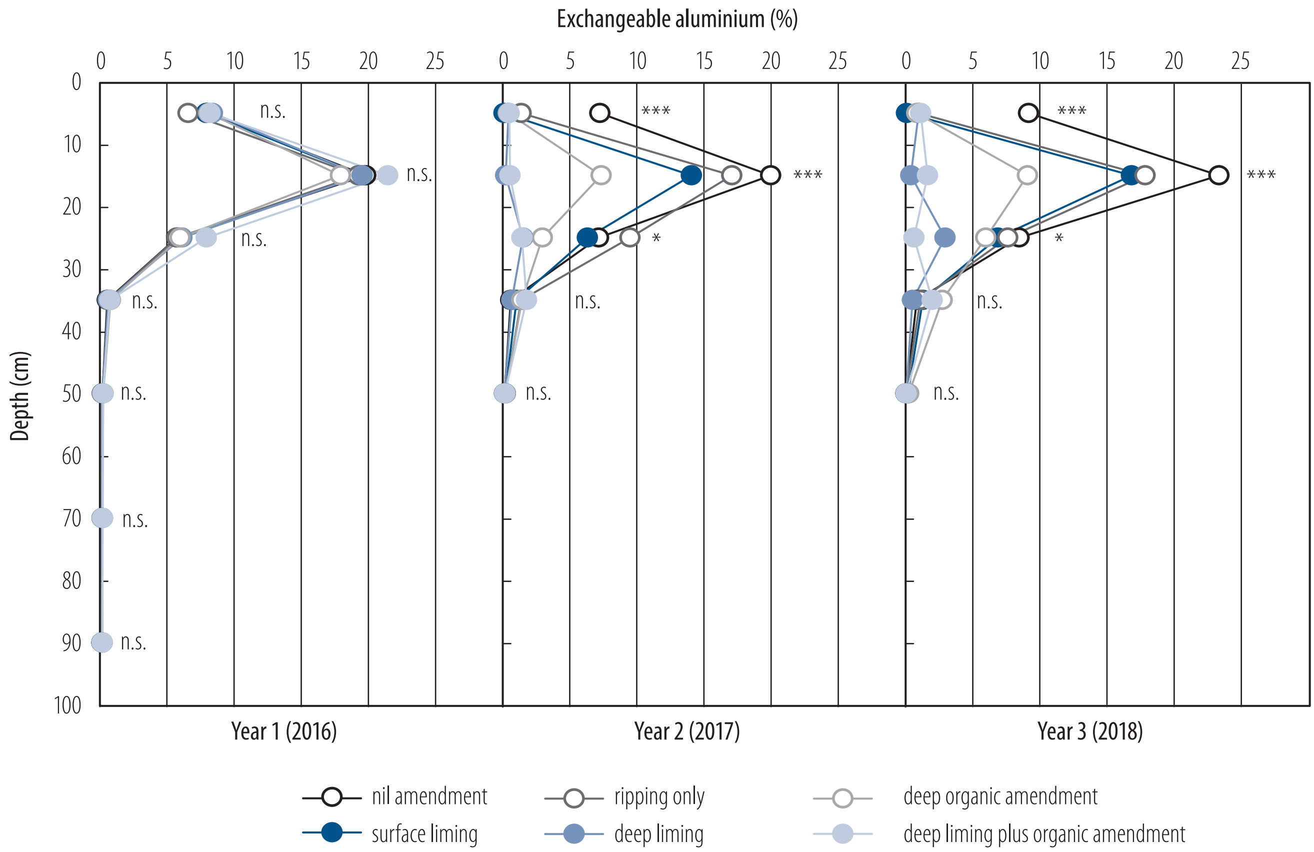



Figure 3. Soil exchangeable Al (%) under different soil amendment treatments in autumn in years 1–3.
**, P<0.05; **, P<0.01; ***, P<0.001; n.s., not significant.*

### *Soil mineral nitrogen (N)*

There was significantly more soil mineral N at 0–60 cm under deep OA treatments with and without lime in both 2017 and 2018 ($P<0.001$) compared with other treatments without organic amendments (Figure 4). On average, there was more than 100 kg of additional mineral N/ha available in the deep OA and deep liming plus OA treatments compared with all other treatments in autumn 2017 and 2018 (Figure 4). The soil mineral N was up to 278 kg N/ha in the deep OA treatment in autumn 2018.

There was no difference in soil mineral N between treatments in any depths in 2016. In autumn 2017, two treatments with OA had significantly higher soil mineral N at all depths compared with other treatments due to extra organic N from OA (Figure 5). In autumn 2018, the difference in soil mineral N between treatments with and without OA became smaller, but was still significant at all depths, particularly at 40–60 cm. This provides some evidence of movement of soil mineral N down the soil profile, i.e. nitrate leaching in those treatments with deep OA.

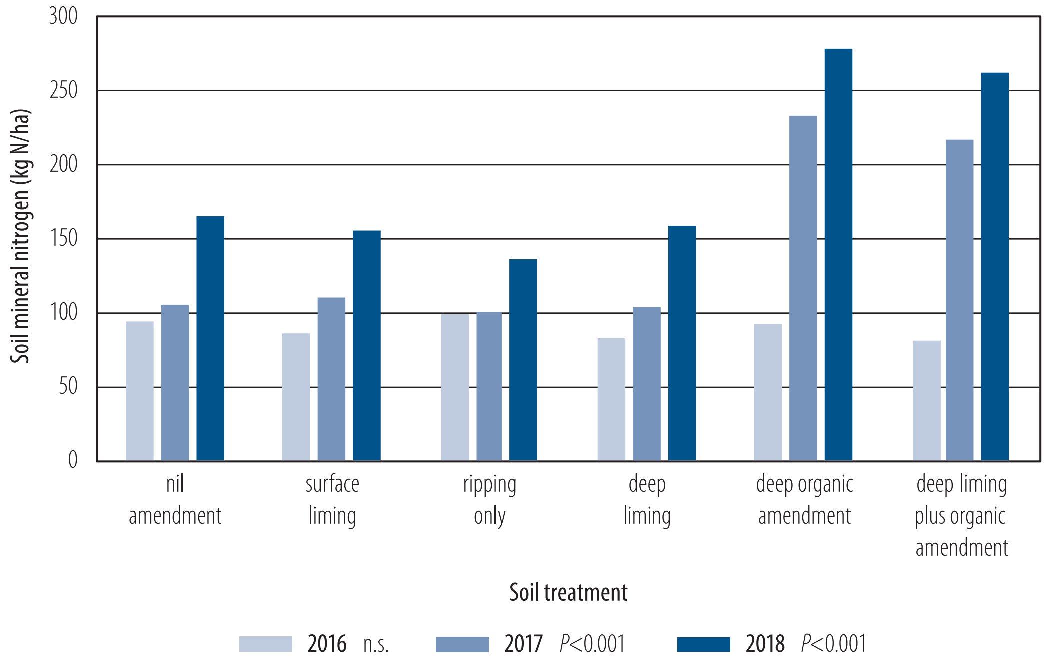



Figure 4. Soil mineral N (kg/ha) in 0–60 cm soil profile under different soil amendment treatments in autumn in years 1–3.

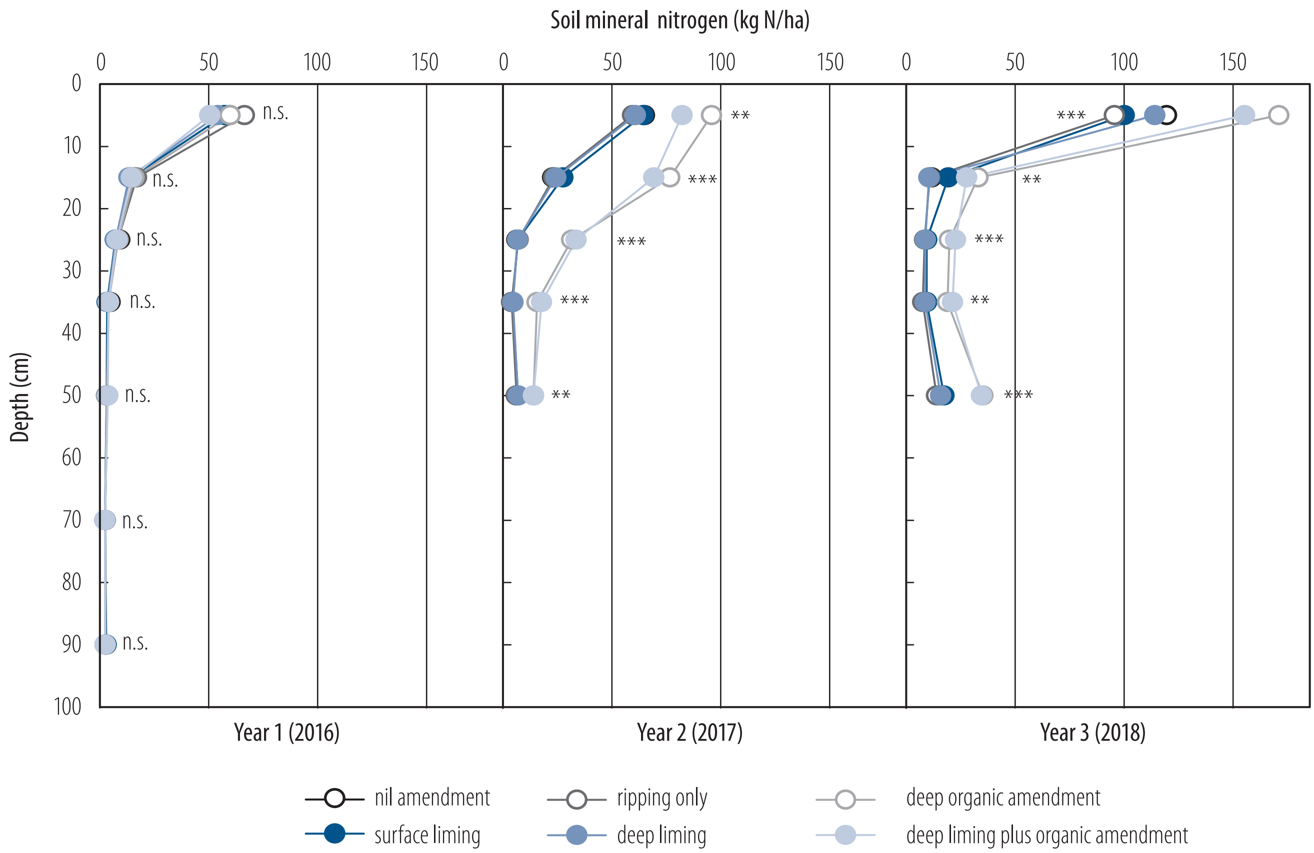



Figure 5. Soil mineral N (kg/ha) in soil profile under different soil amendment treatments in autumn in years 1–3.
**, P<0.05; **, P<0.01; ***, P<0.001; n.s., not significant.*

*Colwell phosphorus (P)*

There were no differences in Colwell P at any depth in any year except at 10–20 cm in year three. At the site, 15 kg/ha of fertiliser P as DAP was applied at sowing each year. Phosphorus remained at a similar level across three years (Figure 6).

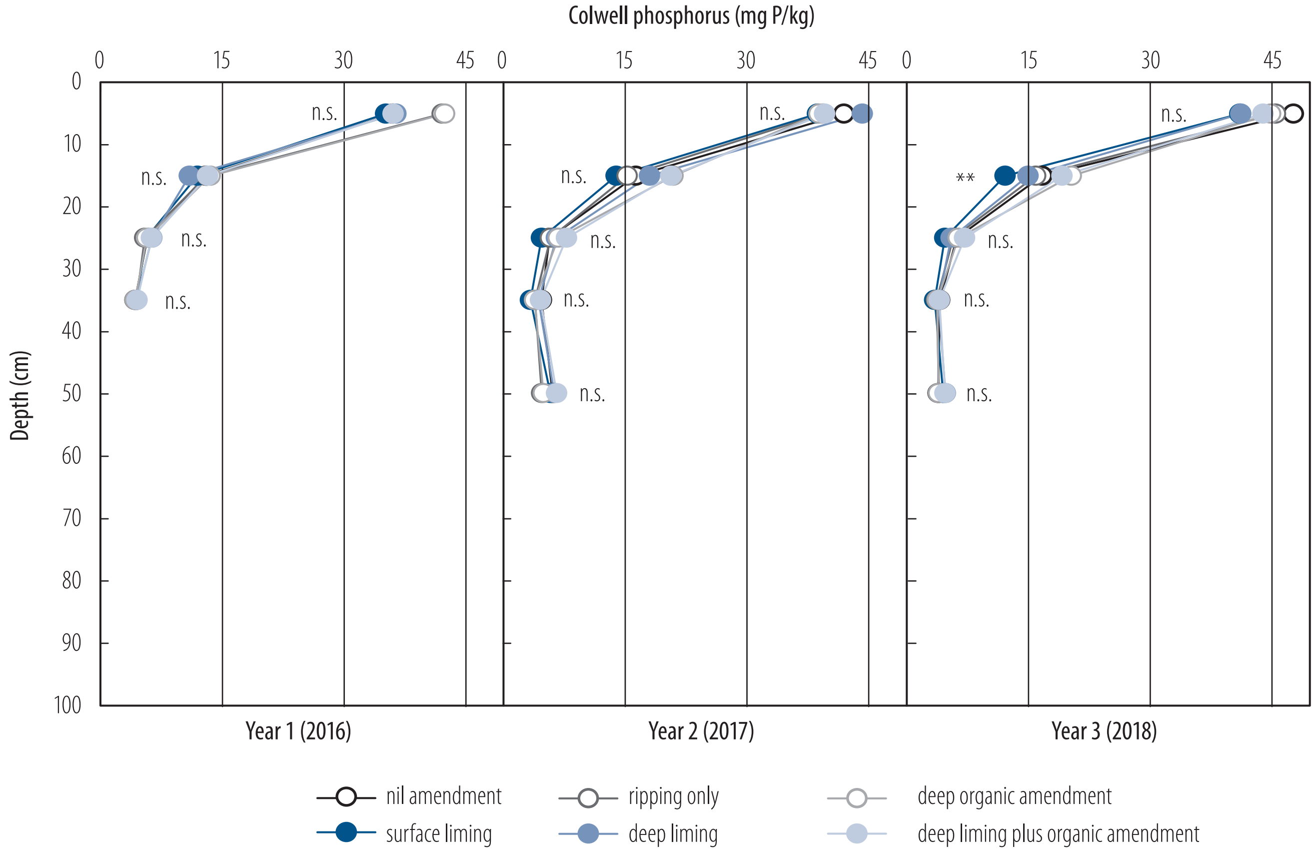



Figure 6. Soil Colwell P (mg/kg) in soil profile under different soil amendment treatments in autumn in years 1–3.
**, P<0.05; **, P<0.01; ***, P<0.001; n.s., not significant.*

### Rooting depth and root density

There was no significant difference in average maximum rooting depth between treatments. Canola was the deepest rooting, reaching 145 cm deep. Pulses (field pea or faba bean) had the shallowest rooting depth (<100 cm deep in general), whereas wheat and barley rooting depths were intermediate (Figure 7). Figure 7 shows that in general, in a wet year (2016), rooting depth was shallower than in a dry year (2018).

There was large variation in root density between treatments at various depths for all four crops (Figure 8). Root density decreased with increased soil depth in general, with the majority of roots located at 0–10 cm for all crops, particularly in dry years. There were considerably fewer roots below 80 cm for pulse crops, compared with the relatively high root density at 80–100 cm for canola and barley crops (Figure 8).

One of the surprising findings from the root density measurements was that all crops developed a dense root system in the top 10 cm (Figure 8) rather than allocating more resources to developing a deep root system as perennial plants do in dry years. In both 2017 and 2018, the soil profile was so dry that plants relied on growing season rainfall. This could be one of the plants' survival strategies, i.e. to use limited water at the soil surface more efficiently rather than allocating valuable resources to search for deep moisture in deep soil.

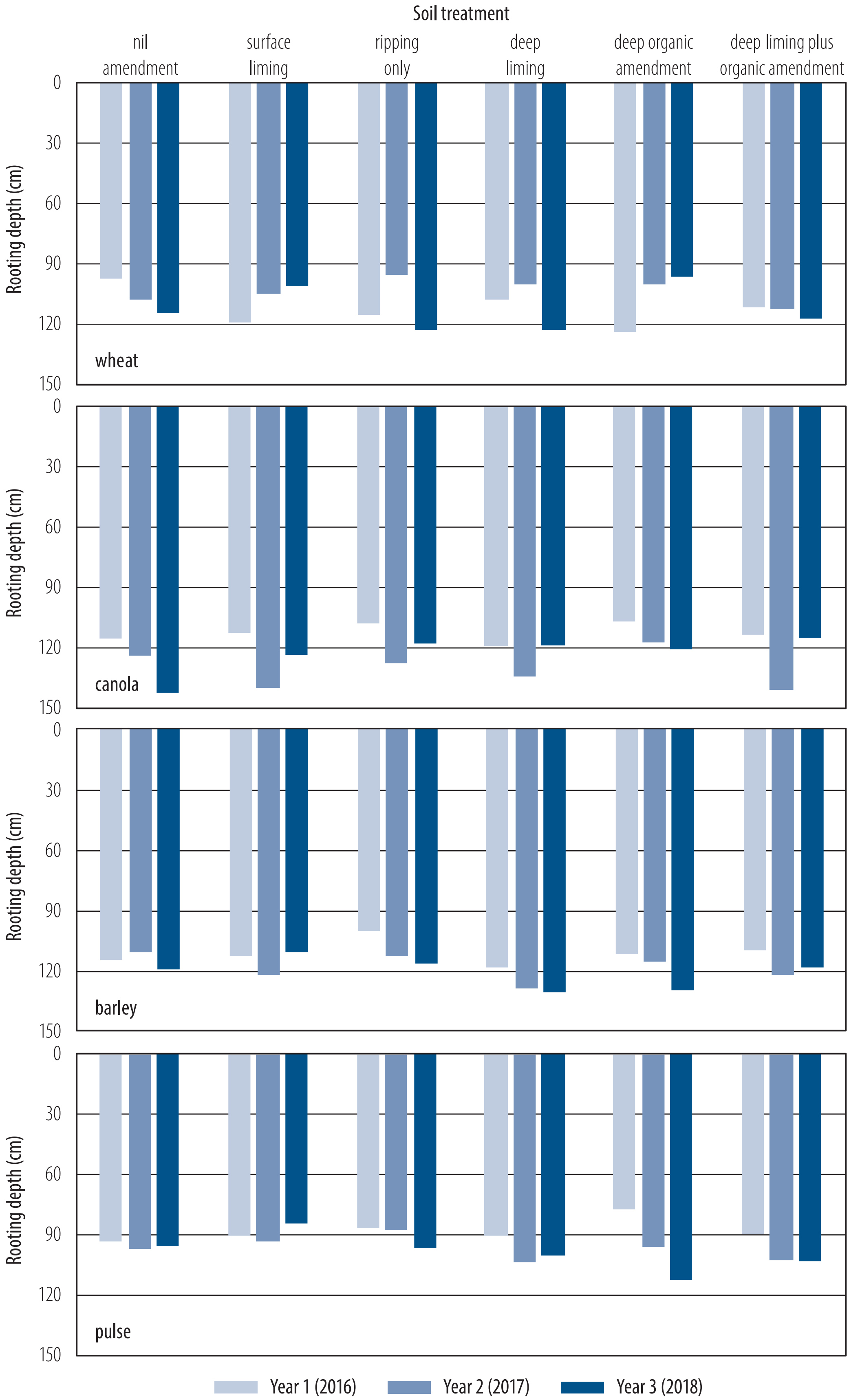



Figure 7. Maximum rooting depth (cm) for each crop in the rotation under different soil amendment treatments at crop anthesis in years 1–3.

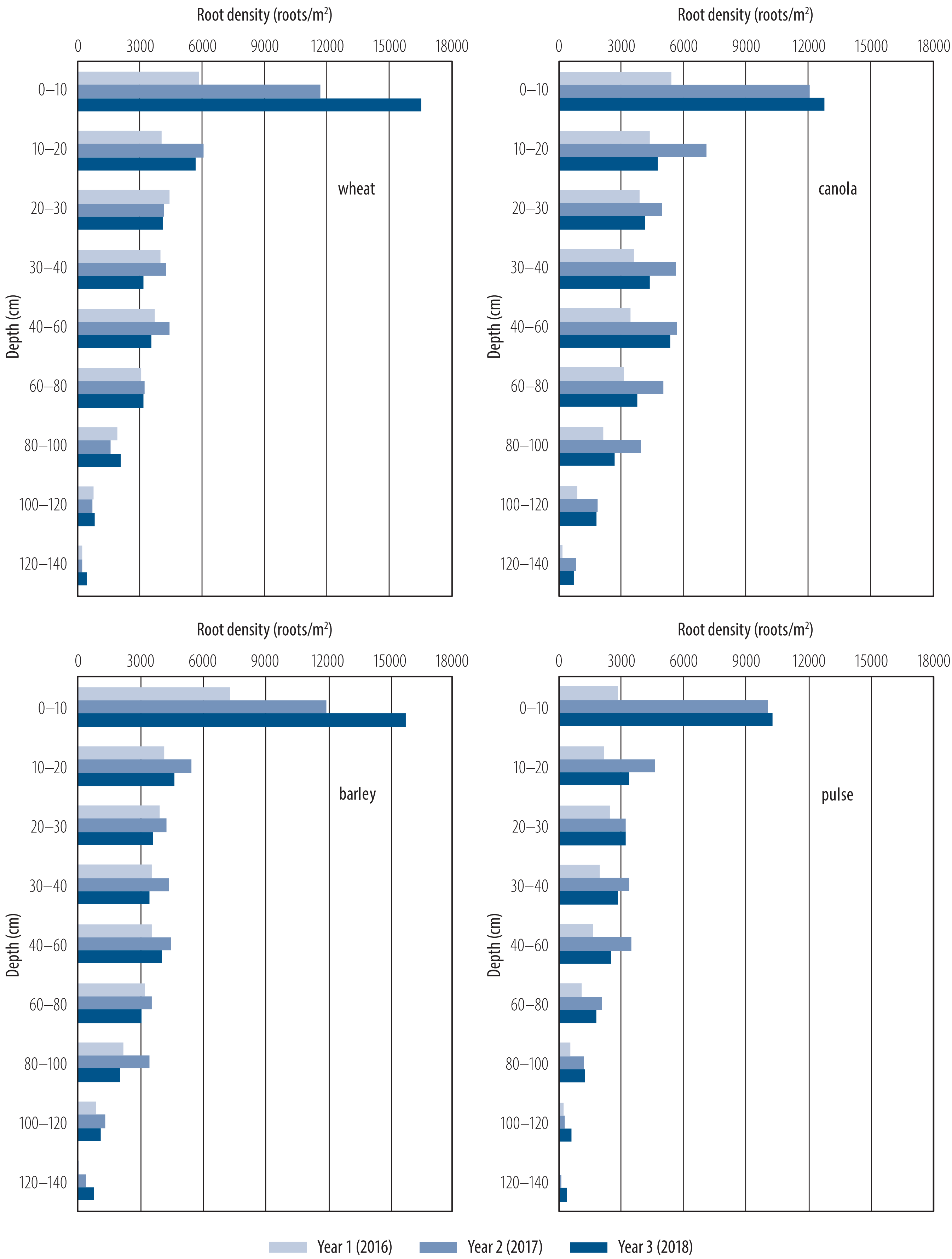



Figure 8. Root density (roots/m²) for each crop in the rotation under different soil amendment treatments at crop anthesis in years 1–3.

### Soil volumetric water content and available soil water

*Soil volumetric water content*

The soil volumetric water content had a strong seasonal pattern – generally following the rainfall pattern but dependent on crop growth (Figure 9). Most changes in the soil water occurred above 40 cm, where most of the plant roots were concentrated (Figure 8). Below 65 cm, the soil moisture remained relatively constant after the soil profile was replenished in 2016. Averaged across all crops, there were no significant differences in soil volumetric water content between treatments at any depths.

*Available soil water*

There was strong seasonal variation in ASW in the 15–40 cm depth (Figure 10) and 65–140 cm depth (Figure 11), reflecting the rainfall pattern and crop growth stages.

In year one, ASW peaked at the end of September, then decreased sharply for all crops in the 0–40 cm depth due to high evapotranspiration in the grain filling period, but decreased less dramatically below 65 cm in the soil profile.

- There was more ASW under the field pea crop at the end of November as that crop matured, and also because of the shallower root system compared with other crops (Figure 7). There was not much difference in ASW between treatments for the field pea crop (Figure 10).
- It appeared that ASW was less under the deep liming plus OA treatment for wheat and canola crops than that under deep OA for barley crops in the 15–40 cm depth at crop maturity. ASW was lower under the deep liming treatment with wheat crop, than under deep liming plus OA treatment with the canola crop.
- The rip only treatment under the barley crop had the least ASW compared with other treatments (Figure 11). In the 65–140 cm depth, there were large differences between treatments for all crops, particularly after crops were harvested.

In year two, ASW in the 15–40 cm depth stayed at a similar level until the end of August when the crop growth rate increased rapidly (Figure 10). During spring, ASW was at a deficit due to vigorous crop growth and limited rain. The early summer rain re-filled the soil profile to levels that varied across crops and treatments. Below 65 cm, ASW remained relatively constant for all crops apart from spring, when ASW reduced slightly, indicating that the crops extracted soil water from deep in the soil profile (Figure 11).

- Under the canola crop, the deep liming treatment had the lowest ASW in the 15–40 cm depth during the growing season, but significant rain late in the growing season in October and November reduced the treatment difference in ASW.
- For the wheat crop, surface liming and deep liming plus OA had less soil moisture deficit in spring than the other treatments (Figure 10).
- There was less variation in ASW for the barley and faba bean crops between treatments apart from large seasonal variation than for the canola and wheat crops (Figure 10). Deep in the soil profile below 65 cm, the treatment difference in ASW was more obvious than in the shallow soil profile for all crops.
- Under the canola crop, deep liming had the lowest ASW, whereas deep liming plus OA had the highest ASW throughout the season. In contrast, under the barley and faba bean crops, the deep liming plus OA treatment had the lowest ASW, but under the wheat crop, the deep OA had the lowest ASW throughout the season (Figure 11).

In year three, ASW in the 15–40 cm depth depended very much on previous crops and the growth stages of the current crops (Figure 10). ASW was generally lower under the barley and wheat crops, but higher under the pulse (field pea) and canola crops among crops (Figure 10). In general, there was not much difference in ASW in the 15–40 cm depth between treatments in any crop until harvested. There was a water deficit under the wheat and canola crops in spring. In the 65–140 cm depth, the wheat and canola crops drew more soil water from deep in the soil than barley or field pea (Figure 11).

- The barley crop, following wheat and canola, had the lowest ASW compared with other crop sequences, with a water deficit for most of the growing season and summer period.
- In contrast, field pea, with a shallow root system, had the highest ASW among crops despite the previous crops being canola and barley.
- There was not much difference in ASW between treatments for the barley crop. However, the surface liming and ripping only treatments had higher ASW throughout season under field pea compared with the other treatments.
- Under wheat, deep liming had the highest ASW compared with the other treatments.
- With the canola crop, the deep OA treatment had the lowest ASW among other treatments, but the ripping only treatment had the highest ASW between treatments (Figure 11).

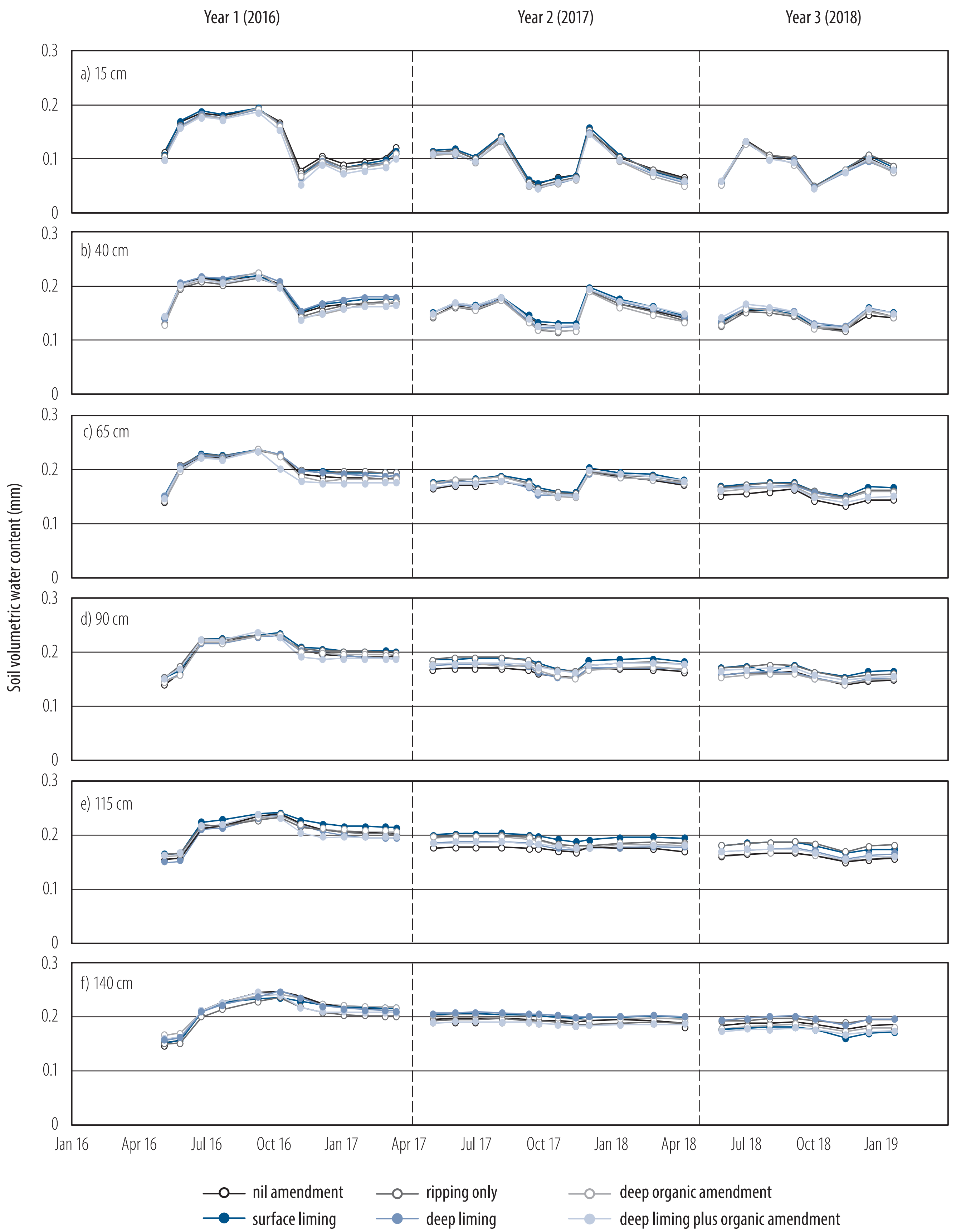



Figure 9. Soil volumetric water content (mm) for each crop in the rotation under different soil amendment treatments over three growing seasons.

Nutrition & soils

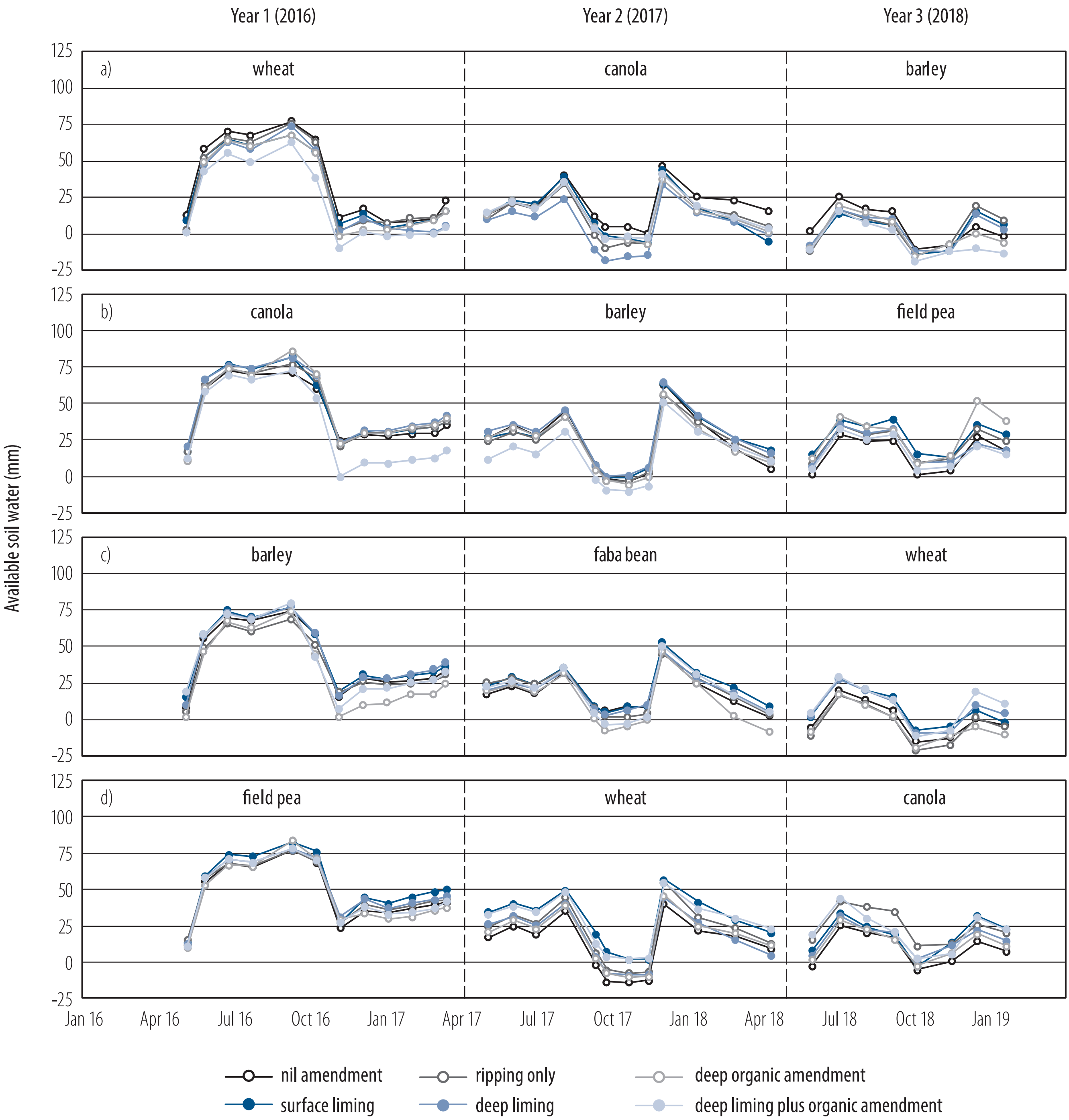



Figure 10. Available soil water (mm) at 15–40 cm for each crop in the rotation under different soil amendment treatments over three growing seasons.

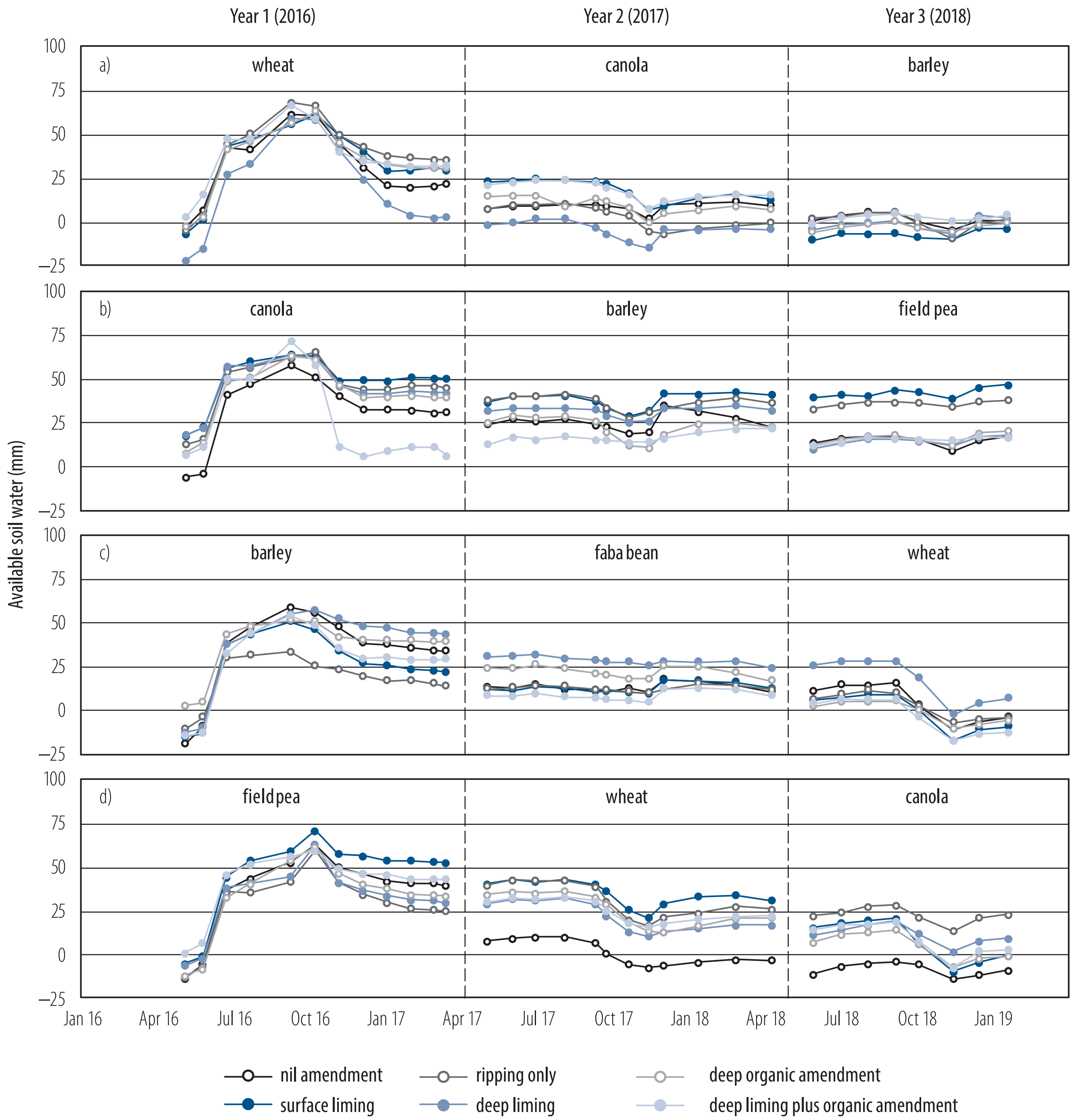



Figure 11. Available soil water (mm) at 65–140 cm for each crop in the rotation under different soil amendment treatments over three growing seasons.

Nutrition & soils

### Agronomic performance

*Seedling count*

At the seedling stage, there was no significant difference in seedling density for any crops, except for barley, where the two treatments with deep OA had higher seedling density (Figure 12). No treatment difference in seedling density for any crop was likely due to the extremely dry conditions during crop establishment in year two and throughout year three. The site only received 269 mm and 173 mm of rain during the growing season (April–October) in years two and three, respectively (Figure 1).

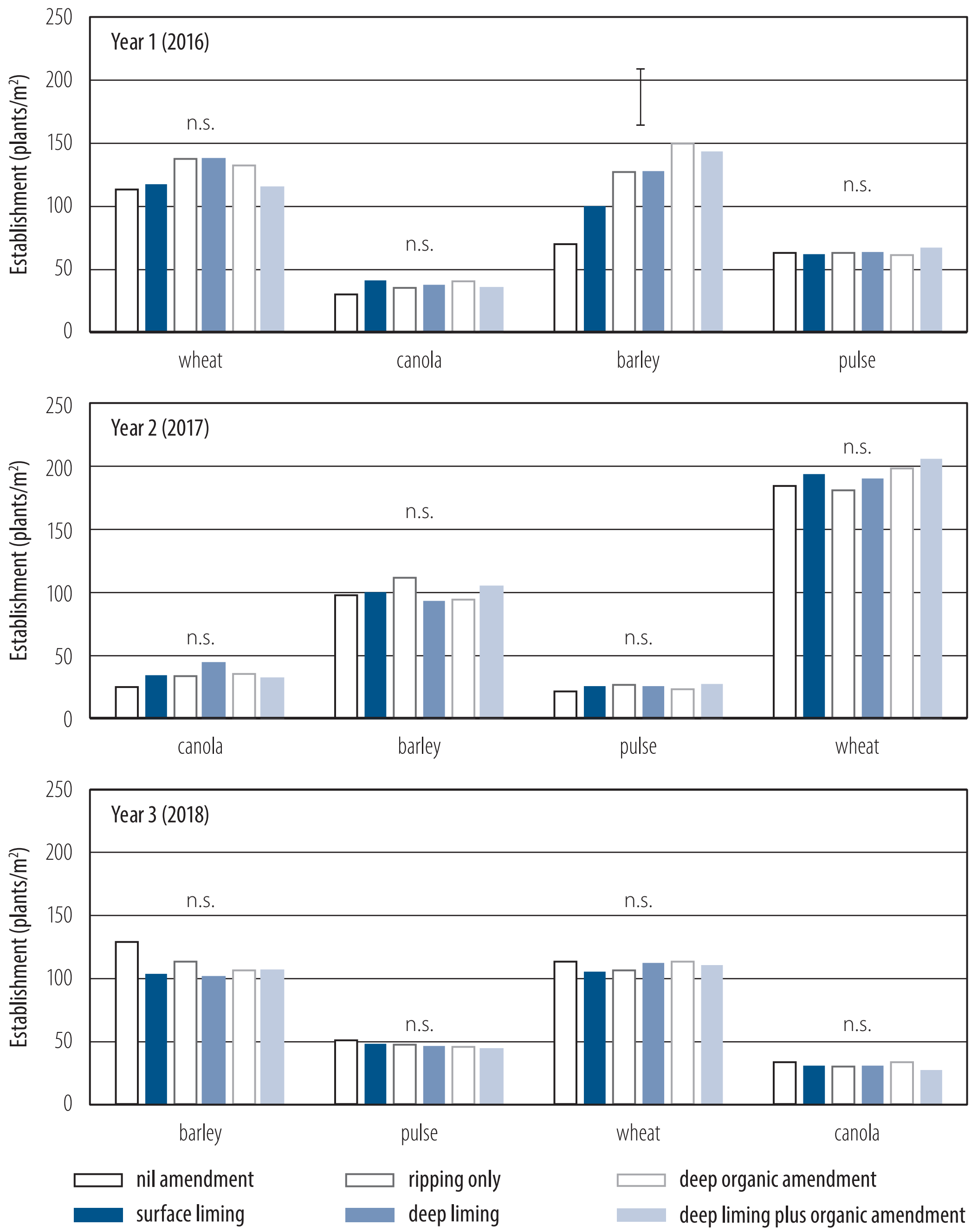



Figure 12. Seedling density (plants/$m^2$) at crop establishment in response to different soil amendments in years 1–3. *Vertical bar represents least significant difference at P = 0.05, n.s., not significant.*

*Anthesis dry matter*

At anthesis, there were significant differences in DM for all crops in year one (2016), but no differences were found in years two or three (Figure 13). Soil water was not limiting in year one and treatment differences were most likely attributable to increased nutrient supply from those treatments with OA. In years two and three, the most limiting factor was soil water. There was no effect of soil treatment on anthesis DM, although there was significantly more soil mineral N at 0–60 cm at sowing in autumn under deep OA treatments with and without lime compared with other treatments (Figure 4).

*Harvest dry matter and grain yield*

In year one, the dramatic crop biomass responses observed under treatments with OA at anthesis for the canola and barley crops did not translate into grain yield at harvest, due to severe lodging (Figure 13). In 2017 and 2018, there were no significant differences in grain yield for any crop (Figure 13), which is most likely due to severe moisture stress in both years (Figure 10). The site only received 269 mm and 173 mm of rain during the growing seasons (April–October), respectively, compared with a long-term average growing season rainfall of 332 mm (Figure 1). Canola yielded less than 1 t/ha of grain in both years, whereas faba bean yielded about 1 t/ha grain in year two and field pea had less than 0.8 t/ha in year three (Figure 14). Cereal crops had higher protein under deep OA treatments ($P<0.05$) in both wet and dry years simply due to high available soil mineral N (Figure 4).

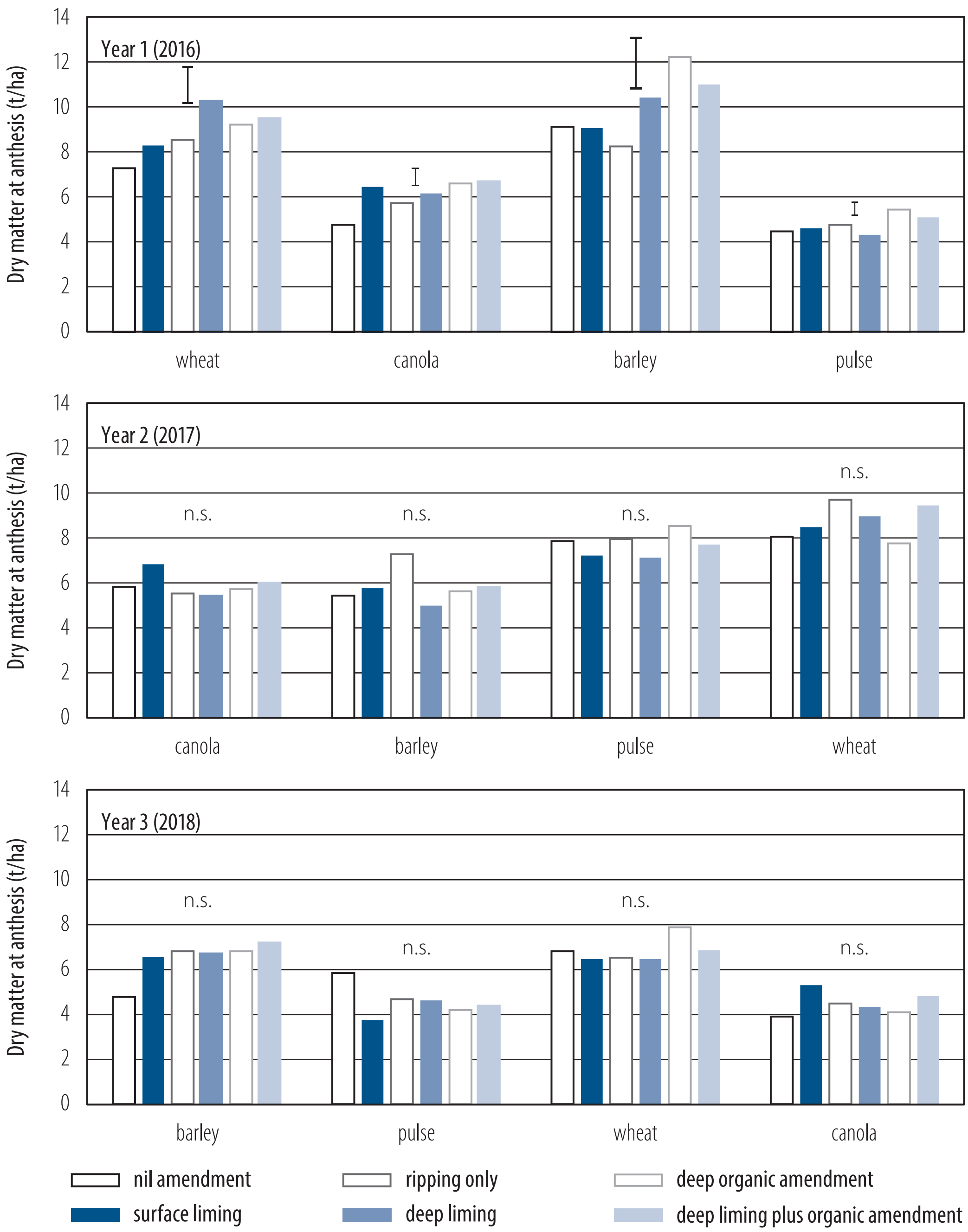



Figure 13. Crop dry matter at anthesis (t/ha) in response to different soil amendments in years 1–3. *Vertical bars represent least significant difference at P = 0.05. n.s., not significant.*

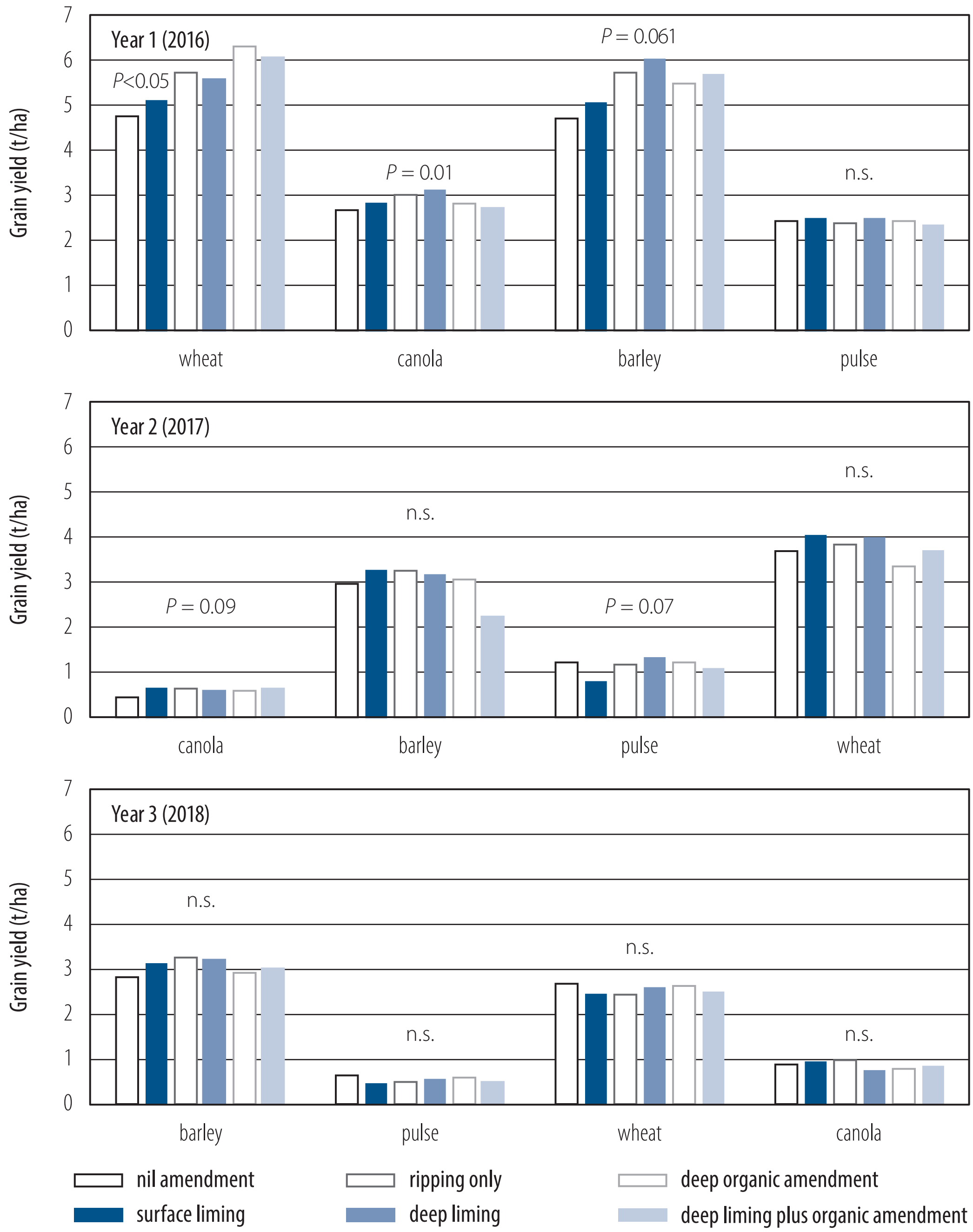



Figure 14. Grain yield (t/ha) in response to different soil amendments in years 1–3.
*Vertical bars represent least significant difference at P = 0.05. n.s., not significant.*

## Conclusions

Lime is the most effective amendment to increase pH and reduce exchangeable Al%. Deep placement of organic amendments had a limited effect on soil pH, but significantly reduced the exchangeable Al percentage. The nutrients in lucerne hay pellets, particularly N, increased soil mineral N significantly, but its effectiveness depended on available soil moisture. In dry years, no yield improvement was found despite more soil mineral N being available at sowing.

## References

Butterly C, Baldock J and Tang C 2010a. Chemical mechanisms of soil pH change by agricultural residues. *Soil Solutions for a Changing World: 19th World Congress of Soil Science*, Brisbane, Australia, (eds RJ Gilkes and N Prakongkep), pp. 1271–1274, International Union of Soil Sciences.

Butterly CR, Baldock JA, Xu J and Tang C 2010b. Is the alkalinity within agricultural residues soluble; Jian–Ming Xu and Pan Ming Huang (eds). *Molecular Environmental Soil Science at the Interfaces in the Earth's Critical Zone*, pp. 314–315.

Butterly C and Tang C 2018. Evaluating rates of organic amendments with lime for treating acid soils. Subsoil factsheet, Issue 15, NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/846782/subsoil-factsheet-no.15-ltu-organic-amendment.pdf, accessed on 3 July 2019.

Haynes RJ and Mokolobate MS 2001. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutrient Cycling in Agroecosystems*, vol 59, pp. 47–63.

Isbell RF 1996. *The Australian Soil Classification*. CSIRO Publishing: Melbourne.

Li G and Burns H 2016. Managing subsoil acidity: 3-D Ripping Machine. NSW Department of Primary Industries, Orange, NSW, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/689152/Subsoil-Factsheet-No.2_Ripping-machine.pdf, accessed on 3 July 2019.

Nguyen HH, Moroni JS, Condon JR, Zander A and Li G 2018. Increasing subsoil pH through addition of lucerne (*Medicago sativa L.*) pellets in the surface layer of an acidic soil. *Proceedings of the 10th International Symposium on Plant-Soil Interactions at Low pH*, Putrajaya, Malaysia, pp. 51–53.

Smit AL, Bengough AG, Engels C, Noordwijk Mv, Pellerin S and Geijn SCvd 2000. *Root Methods*. Springer Berlin Heidelbery.

## Acknowledgements

This experiment was part of the 'Innovative approaches to managing subsoil acidity in the southern region' project, DAN00206, 2015–20, with joint investment by NSW DPI and GRDC. Our thanks extend to the property manager, Tony Flanery, and land owner, Ian Friend, of Ferndale, Dirnaseer, NSW for their ongoing cooperation since 2016.