Addressing subsoil acidity in the field with deep liming and organic amendments: Research update for a long-term experiment

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Abstract

A long-term field experiment was established in 2016 to manage subsurface soil acidity through innovative amelioration methods with the aim to increase productivity, profitability and sustainability. Deep placement of lime increased soil pH and reduced exchangeable Al% at the depth where lime was placed, but there was no evidence to show vertical alkalinity movement during the first 3 years of the experiment. Deep placement of lucerne pellets did not increase soil pH as much as expected, but reduced exchangeable Al%. Significant yield improvement was recorded from deep placement of lucerne pellets in a wet year (2016) but not in dry years experienced in 2017 and 2018, although large amount of mineral nitrogen was measured in autumn in 2017. Crop performance and soil chemical, physical and biological properties will be continually monitored to understand plant-soil interactions, the factors driving the differences in crop response to various treatments, and the long-term residual value of soil amendments.

Key Words

Crop rotation, organic amendment, acidity amelioration

Introduction

Subsurface soil acidity is a major constraint to crop productivity in the high rainfall zone (500–800mm) of south-eastern Australia (Scott *et al.* 2000). Approximately 50% of Australia's agriculture zone (~50M ha) has a surface soil pH in calcium chloride (pH, hereafter) < 5.5 and half of this area also has subsoil acidity (SoE 2011). The surface application of lime is a common practice used to combat soil acidity. However, lime moves very slowly down the soil profile so subsoil acidity will only be ameliorated after decades of regular application (Norton *et al.* 2018; Li *et al.* 2019). More aggressive methods, such as deep ripping with direct application of a liming amendment to the acidic layer, are required to achieve more rapid amelioration in the subsurface layers. However, these aggressive methods may also be considered expensive and inefficient as the soil amendment might be concentrated in the ripping slot rather than homogenized in the whole profile.

It has been reported that organic amendments could be used to reduce subsoil acidity because the decarboxylation reactions that they promote have the potential to increase soil pH, decrease Al toxicity and generally improve conditions for root growth (Tang *et al.* 2013). However, this has not previously been tested in a field environment in the target region.

A long-term field experiment was set up in 2016 to *a*) manage subsoil acidity through innovative amelioration methods that might increase productivity, profitability and sustainability; and *b*) study soil processes, such as the changes in soil chemical, physical and biological properties under vigorous soil amelioration techniques over the longer term.

Methods

The site is located at "Ferndale", Dirnaseer (34.6411S, 147.8282E), west of Cootamundra, NSW on a Red Chromosol soil (Isbell 1996). The experiment is a fully phased split-plot design replicated 3 times with crop as main plot (4 crops) and soil amendment as subplot (6 soil treatments, Table 1). The crop sequence is wheat (*Triticum aestivum*), canola (*Brassica napus*), barley (*Hordeum vulgare*), and pulse [faba bean (*Vicia faba*) or field peas (*Pisum sativum*), depending on seasonal conditions]. There were 6 treatments with 3 contrasts, *a*) surface liming vs deep liming, *b*) deep liming vs deep organic amendments, and *c*) deep liming with and without organic amendments (Table 1). The lime used was super fine lime (F70, Omya Australia) with 98% neutralised value. Soil treatments were implemented using the 3D Ripper designed and fabricated by NSW Department of Primary Industries (Li and Burns 2016a). Seedling numbers at establishment, crop DM at anthesis and harvest, grain yield and quality were measured annually. Soil samples were taken using small soil cores (25mm in diameter) at 0-60cm (12 cores per plot) and large cores (44mm in diameter) at 60-100cm (2 cores per plot), bulked at 10cm increments from 0-40cm, and 20cm increments from 60-100cm for each plot. Deep soil cores were only taken at the start of crop cycle at years 1, 5, 9 (See experimental design in Li and Burns 2016b).

Table 1. Soil amendment and treatment description

Treatment	Depth (cm)	Target pH[a]	Lime rate (t/ha)	LP rate (t/ha)	Treatment description
1. Nil amendment	0-10	-	-	-	No amendment
	10-30	-	-	-	
2. Surface liming	0-10	5.5	3.8	-	Lime incorporated into 0-10cm
	10-30	-	-	-	
3. Ripping only	0-10	5.0	2.5	-	Lime incorporated into 0-10cm
	10-30	-	-	-	Deep ripping to 30cm
4. Deep liming	0-10	5.0	2.5	-	Lime incorporated into 0-10cm
	10-30	5.0	3.0	-	Deep placement of lime at 10-30cm
5. Deep LP[b]	0-10	5.0	2.5	-	Lime incorporated into 0-10cm
	10-30	5.0	-	15	Deep placement of LP at 10-30cm
6. Deep liming plus LP	0-10	5.0	2.5	-	Lime incorporated into 0-10cm
	10-30	-	3.0	15	Deep placement of lime and LP at 10-30cm

[a] Target pH represents an 8 year average as estimated from incubations and estimated acidification rates

[b] LP, lucerne pellets as organic amendments

Results and discussion

Soil pH

The average soil pH was 4.52, 4.31 and 4.70 at 0-10cm, 10-20cm and 20-30cm, respectively, at the start of experiment. There was no difference in soil pH between treatments at any depth in year 1 prior to treatments being imposed. In autumn 2017, one year after treatments were applied, surface liming increased pH to 5.9 at 0-10cm. The deep limed treatment with and without lucerne pellets significantly increased soil pH at 10-20cm and 20-30cm as expected. Similar trends were observed in 2018 (Figure 1).

However, the deep organic amendment treatment did not increase pH as high as pilot lab/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 more variable. In addition, nearly all controlled environment experiments were conducted over a short duration, up to 3 months. It is reported that decomposition of organic materials increased soil pH initially (Butterly *et al.* 2010b), whereas the nitrification process decreased soil pH (Butterly *et al.* 2010a). The net effect would keep soil pH unchanged assuming the magnitude of changes cancel out each other. A number of soil column experiments demonstrated that the soluble component from organic materials moves down the soil profile with alkali if combined with lime (Butterly *et al.* 2016; Nguyen *et al.* 2018). However, there is no evidence to show the alkalinity being moved vertically under lime plus organic amendment in the first 3 years of the current field experiment.

Exchangeable Al

The exchangeable Al% (Al as percentage of effective cation exchange capacity) was 19.6% and 6.2% at 10-20 and 20-30cm in 2016 prior to experimentation. The deep liming treatments, either with or without organic amendment, reduced exchangeable Al to less than 2% in 2017 and 3% in 2018 at 10-30cm. Although the organic amendment did not increase soil pH, it did reduce exchangeable Al% significantly at 10-30cm compared to those treatments without deep placement of soil amendments. Haynes and Mokolobate (2001) suggested that the soluble organic molecules from organic amendment could combine with Al^{3+} to form insoluble hydroxy-Al compounds. The exchangeable Al remained high in the 10-30cm depths under ripping only and surface lime treatments. The nil amendment treatment had the highest exchangeable Al at all 3 depths at 0-30cm.

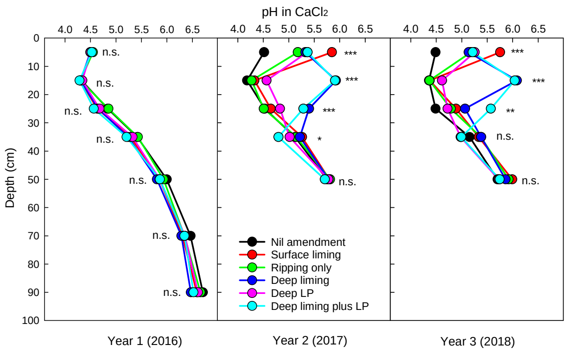

Figure 1. Soil pH under different soil amendment treatments in autumn in years 1-3

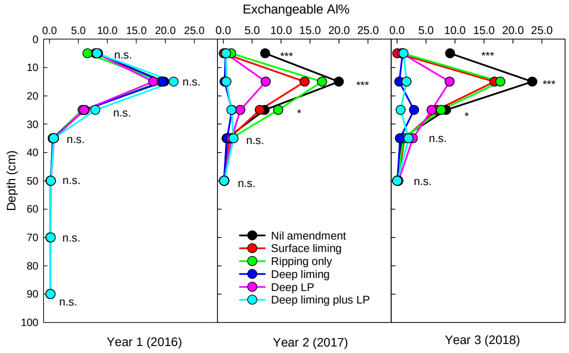

Figure 2. Soil exchangeable Al% under different soil amendment treatments in autumn in years 1-3

Anthesis DM

At anthesis, there were significant differences in DM for all crops in year 1, but no differences were found in years 2 and 3 (Figure 3). There was no soil moisture limitation in year 1 and treatment differences were likely attributed to increased nutrient supply from those treatments with lucerne pellets. In years 2 and 3, the most limiting factor was soil moisture. There was no effect of soil treatment on anthesis DM although there was significantly more soil mineral N at 0-60cm under application of deep lucerne pellets with and without lime at sowing in autumn (data not shown).

Grain yield

In year 1, the dramatic crop biomass responses observed under treatments with lucerne pellets at anthesis in canola and barley crops did not translate into high grain yield at harvest (Figure 4) due to severe lodging. In 2017 and 2018, there were no significant differences in grain yield in any crops (Figure 4) due to moisture stress. The site only received 269 and 173mm of rainfall during the growing seasons from April to October, respectively, compared to a long-term average growing season rainfall of 332mm. Canola had less than 1 t/ha of grain yield in both years, whereas faba bean had about 1 t/ha grain in year 2 and field pea had less than 0.8 t/ha in year 3. Cereal crops tended to have higher protein under deep lucerne pellet treatments ($P < 0.05$) in both wet and dry years simply due to the extra soil mineral N available to crops (data not shown).

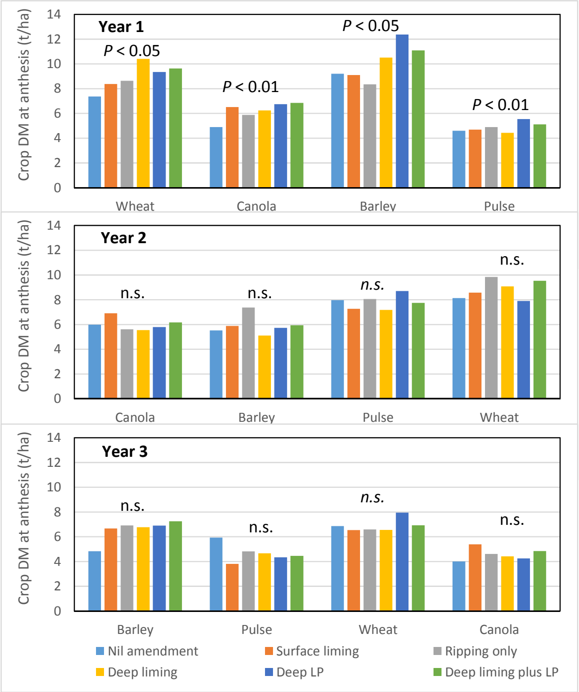

Figure 3. Crop dry matter at anthesis (t/ha) in response to soil amendments in years 1-3

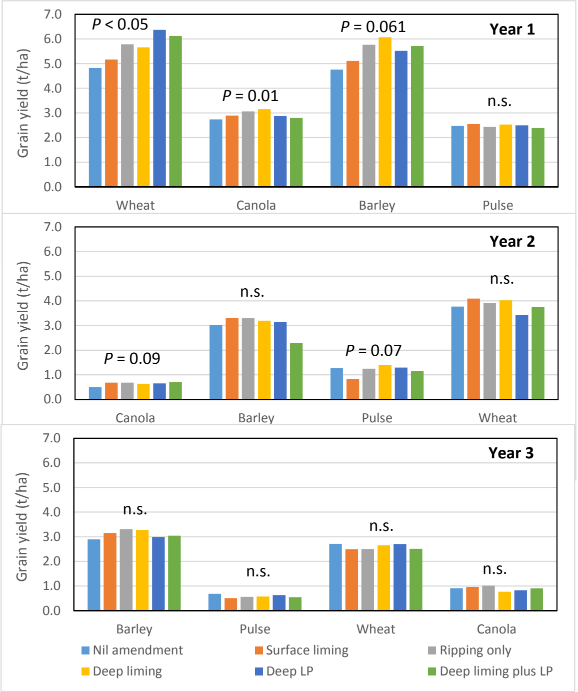

Figure 4. Grain yield (t/ha) in response to different soil amendments in years 1-3

Conclusion

Deep placement of lucerne pellets had limited effect on soil pH, but reduced exchangeable Al% significantly. The nutrients in lucerne pellets, particularly nitrogen, increased soil mineral nitrogen significantly but its effectiveness was dependent upon soil moisture availability. In dry years, no yield improvement was found despite more soil mineral nitrogen being available at sowing.

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