Addressing soil acidity: subsurface soil amendments increasing pH and crop yield at Rutherglen

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Key points

- Deep placement of soil ameliorants applied during 2017 continued to improve soil pH and decreased aluminium (Al) concentrations in the subsurface soil layer during 2019.
- The benefits of soil amendments to soil pH and aluminium concentration remain for future seasons.
- Grain protein increased in treatments that ameliorated acidity and increased soil nutrition.

Introduction

Acidity of subsurface soil (below 10cm from the soil surface) is a major constraint to crop production in the high-rainfall (500–800mm) cropping zone. While acidic surface soil (0–10cm) can be easily and effectively addressed by incorporating lime at the soil surface, amelioration of the subsurface (below 10cm) soil has not been practical.

The current GRDC-funded project *Innovative approaches to managing subsoil acidity in the southern grain region* (DAN00206) aims to identify and evaluate a range of products, which may be used to overcome adverse effects of subsurface soil acidity. These products include alkaline materials, such as lime and dolomite, and novel products, such as magnesium silicate (which reacts to create alkali conditions) or reactive phosphate rock (which can increase pH and release plant-available phosphorus (P) as it dissolves in acidic soil).

Organic amendments, such as lucerne pellets, are known to increase soil pH either by being an alkali source or by enabling alkaline reactions to occur during the decomposition of organics. The influence of these products on the conditions of subsurface acidity (soil pH and toxic aluminium levels) and crop yield were investigated within a field trial established during 2017.

Aim

To quantify the yield limitation caused by subsoil acidity and evaluate innovative soil amendments that act to ameliorate subsurface acidity.

Method

During 2017, a three-year, replicated field trial was established at Rutherglen, Victoria, on a site located adjacent to the Rutherglen–Wahgunyah Road. The site has more than 20 year history of clover pasture, which was grazed and cut for hay. The absence of any lime applications to the site during this time has resulted in highly acidic soil and high aluminium (Al) concentrations in both the surface (0–10cm) and subsurface soil (10–30cm) (Table 1).

The existing pasture was sprayed out and 14 amendment treatments were applied during March 2017 in a randomised block design with three replicates, with plots measuring 5m x 20m (Table 2). Canola was grown during 2017, wheat during 2018 and canola was sown again during 2019.

There were 14 treatments, including 11 deep amendment treatments, to contrast with a nil control (no additions), lime control and surface lime treatments. Apart from the nil control, all other treatments received surface application of superfine lime (neutralising value = 98%) at 1.7t/ha to achieve a soil pH in the 0–10cm of pH 5.0 in order to ameliorate surface acidity. The surface lime treatment received a higher rate (2.7t/ha) of surface-applied lime to achieve a target pH of 5.5 in the surface layer.

Deep amendment treatments included: lime, dolomite, magnesium silicate (MgSi), lucerne pellets, reactive phosphate rock (RPR) and liquid phosphorus (P). The deep amendments were placed approximately 10–30cm deep in the profile at a 50cm row spacing using the 3D Ripper machine engineered by NSW DPI. A deep-ripped control, which had surface lime (pH 5.0) but was deep ripped with no amendment added (deep ripping only), was included to contrast the deep amendment treatments. Deep amendments were applied at rates to achieve a target pH 5.0 based on short-term laboratory incubation studies conducted at Charles Sturt University. Amendments applied at two rates (MgSi,

TABLE 1 Initial pH and exchangeable aluminium percentage of the Rutherglen field trial, January 2017*

Soil depth (cm)	Soil pH ($CaCl_2$)	Al (%)
0–10	4.55	12
10–20	4.22	30
20–30	4.32	10
30–40	5.05	3

* Exchangeable aluminium percentage is determined as the percentage of the measured cation exchange capacity (CEC), which is comprised of aluminium. A value greater than 6 per cent generally indicates aluminium to be likely to cause plant phytotoxicity.

RPR and lucerne pellets) were labelled high and low, for the targeted pH 5.0 rate and half that rate, respectively.

Canola (Hyola 559 TT) was sown on 12 April 2019 at 3kg/ha, with 75kg MAP/ha placed with the seed using a cone seeder on a 25cm row spacing. The site was harvested on 31 November 2019 using a plot harvester. Yield, protein and oil data were statistically analysed using ANOVA and a Student-Newman-Keuls test to determine treatment differences.

The soil from each plot was sampled on 4 December 2019 by taking two 44mm diameter cores on the rip-line and two cores between rip lines to a depth of 140cm. Core samples were divided into depth increments of 0–10, 10–20, 20–30, 30–40, 40–60, 60–80, 80–100, 100–120, 120–140cm, with depth increments from duplicate cores bulked to produce representative soil samples for each sampling depth, on and off the rip-line.

Each soil sample was air-dried and analysed for soil water content, soil pH ($CaCl_2$), exchangeable cations (including aluminium) and available phosphorus. Data for each depth increment were statistically analysed using ANOVA at the 95 per cent confidence interval. Weather data were collected at the experimental site via a data logged weather station.

Results

The experimental site received 263mm rainfall during the growing season (long-term average growing season rainfall is 400mm) and an annual rainfall of 389mm for 2019 (Figure 1). The site experienced 32 nights of negative temperatures.

Soil measurements taken after harvest (December 2019) showed soil pH in the surface (0–10cm) soil ranged from pH 4.4–5.4. A pH of 4.4 was recorded where no lime was applied during 2017, while the pH was approximately 5 where surface lime was applied at 1.7t/ha during 2017. Where lime was applied to the surface at the higher rate of 2.7t/ha (Figure 2) a pH of 5.4 was recorded.

On the treatment row in the 10–20 and 20–30cm layers, large increases in soil pH were recorded relative to the control in the deep-placed lime treatment, resulting in soil pH higher than 6.5 in those layers. Within the 20–30cm layer, the deep lime treatment with phosphorus, magnesium silicate treatment and high rate of reactive phosphate rock treatment were all effective in maintaining a soil pH between 5 and 5.5. These treatments also decreased the aluminium percentage to less than 5 per cent in the 10–20cm layer, which was significantly less than treatments not receiving alkaline amendments in the subsurface soil (i.e. control, deep ripping only, deep phosphorus and surface lime treatments). In the 10–20cm layer, both the deep dolomite and deep lime with phosphorus treatment significantly increased pH compared with the control, however neither of these treatments kept the aluminium percentage below 10 per cent in the 10–20cm layer (Figure 2).

During this third year of the experiment, soil pH in the lucerne pellet treatments were not significantly different to the untreated control in layers below the surface 10cm. For the 10–20cm layer, the aluminium percentage of the lucerne-pellet-treated soil was not significantly different to the control. However, in the 20–30cm layer, the high rate of lucerne pellets created a significantly lower aluminium percentage than treatments that received no added amendments to that layer, despite not increasing soil pH. This may indicate that components of the organic matter can tie up aluminium cations making them unavailable to

TABLE 2 Surface and deep amendment treatments applied at Rutherglen, 2017

Treatment	Surface lime application rate (t/ha)	Target surface pH ($CaCl_2$)	Deep amendment (placed about 10–30cm deep)	Deep amendment application rate (t/ha)
Nil control	0	-	n/a	n/a
Limed control	1.7	5.0	n/a	n/a
Surface lime	2.7	5.5	n/a	n/a
Deep ripping only	1.7	5.0	Deep ripping only	n/a
Deep lime	1.7	5.0	Lime	2.5
Deep dolomite	1.7	5.0	Dolomite	2.3
Deep MgSi (low)	1.7	5.0	Magnesium silicate	4
Deep MgSi (high)	1.7	5.0	Magnesium silicate	8
Deep lucerne (low)	1.7	5.0	Lucerne pellets	7.5
Deep lucerne (high)	1.7	5.0	Lucerne pellets	15
Deep RPR (low)	1.7	5.0	Reactive phosphate rock	4
Deep RPR (high)	1.7	5.0	Reactive phosphate rock	8
Deep P	1.7	5.0	Liquid phosphorus	15kg P/ha
Deep P + deep lime	1.7	5.0	Liquid phosphorus + lime	15kg P/ha + 2.5t/ha Lime

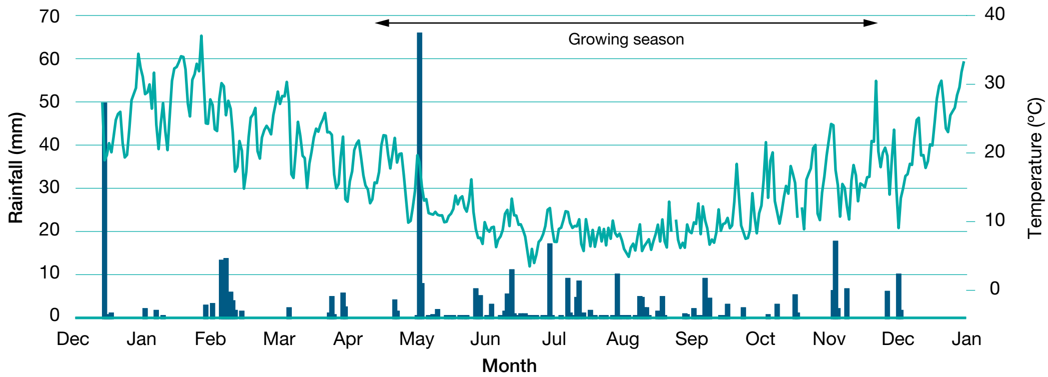

FIGURE 1 Rainfall and average air temperature during the 2019 season at Rutherglen

Note: The growing season (sowing to harvest) is indicated by horizontal arrow at top of figure.

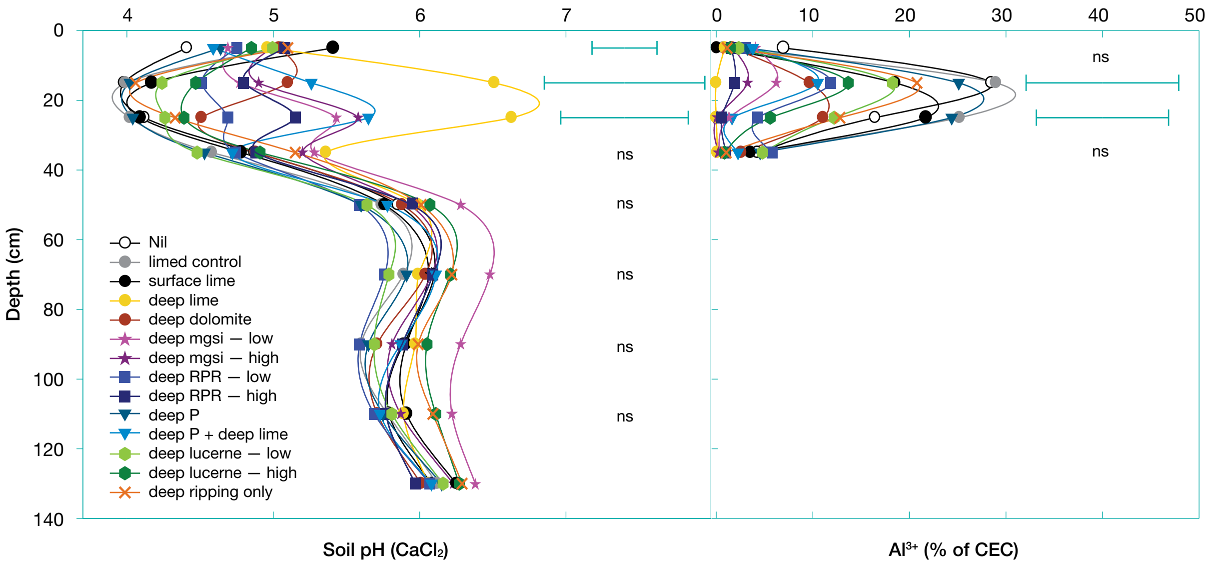

FIGURE 2 Post-harvest soil pH ($CaCl_2$) and exchangeable aluminium percentage (% of CEC) of amendment treatments as sampled from the treatment row at Rutherglen, 2019

Data are means of three replicates of each treatment. Bar represents LSD for pH data at *p*=0.05, ns = not significant.

plants, even at low pH (<5). This may also indicate that lucerne-derived organic compounds are binding with plant-toxic aluminium cations in a way that removes it from solution.

There were no treatment differences in the soil pH of any layer based on soil samples taken between the amendment rows (Figure 3). This provides evidence that lateral movement of amendment alkali, regardless of the form, is negligible.

There were no significant differences between treatments at *P*=0.05.

A strong relationship existed between soil pH and aluminium percentage across all soil layers at this trial site (Figure 4). As soil pH values decreased below pH 5.0, the amount of aluminium in solution increased exponentially, a response which is common in soils of south-east Australia. Some variation from the relationship may exist due to organic

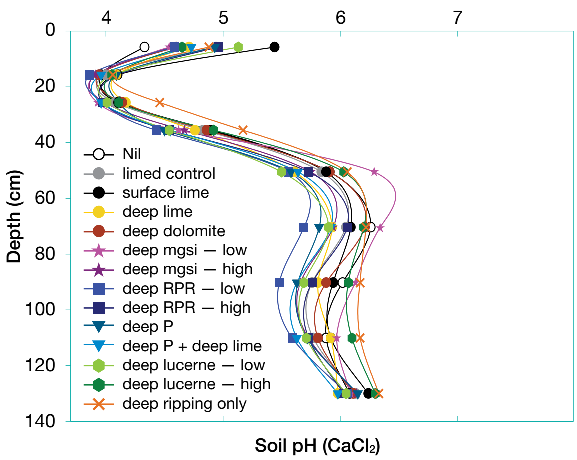

FIGURE 3 Post-harvest soil pH ($CaCl_2$) of amendment treatments as sampled from the mid-row between treatment rows at Rutherglen, 2019

Data are means of three replicates of each treatment.

complexation of Al^{3+}, however based on Figure 4 the effect is minor and the relevance to field conditions over longer periods of time is unknown.

There were no significant differences in yield between treatments in 2019 (Table 3). Yield of all treatments was low relative to yields of more than 2t/ha observed commercially across the region. The poor performance of the 2019 crop was largely due to poor seedling survival following a storm event during early May, two weeks after sowing (Figure 1). This intense rainfall event destroyed surface soil structure and inundated the seed rows, resulting in poor establishment.

Image analysis of drone footage taken on 5 August 2019 showed no treatment difference in the percentage green area of each plot.

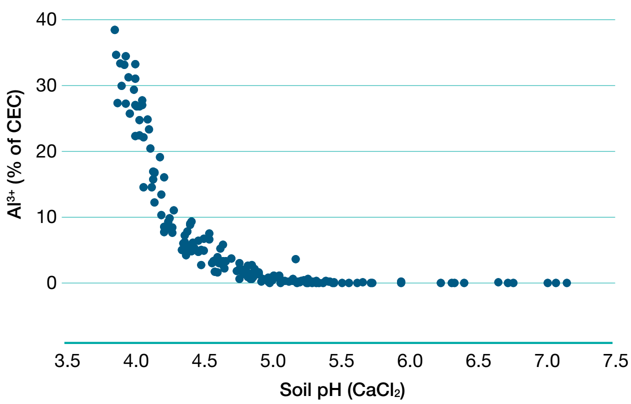

FIGURE 4 The relationship between soil pH and percentage of the cation exchange sites occupied by aluminium cations in soil samples taken at Rutherglen, December 2019

TABLE 3 Harvested yield, protein and oil content of canola grown at Rutherglen, 2019

Treatment	Yield (t/ha)	Protein (%)	Oil (%)
Nil control	1.40 (0.10)	46.6^{a}	42.40^{b}
Limed control	1.21 (0.03)	46.3^{a}	42.57^{b}
Surface lime	1.32 (0.10)	46.4^{a}	41.87^{ab}
Deep ripping only	1.13 (0.04)	46.3^{a}	42.33^{b}
Deep lime	1.14 (0.16)	46.3^{a}	41.73^{ab}
Deep dolomite	1.26 (0.05)	46.8^{a}	41.90^{ab}
Deep MgSi (low)	1.17 (0.06)	47.7^{ab}	42.33^{b}
Deep MgSi (high)	1.22 (0.04)	48.2^{b}	41.97^{ab}
Deep lucerne (low)	1.31 (0.08)	47.3^{ab}	42.47^{b}
Deep lucerne (high)	1.18 (0.10)	47.2^{ab}	41.37^{ab}
Deep RPR (low)	1.19 (0.03)	47.2^{ab}	41.63^{ab}
Deep RPR (high)	1.11 (0.05)	47.3^{ab}	40.53^{a}
Deep P	1.15 (0.23)	46.7^{a}	42.80^{b}
Deep P + deep lime	1.38 (0.08)	46.9^{ab}	42.07^{b}

Note: Within each column means marked with different letters are significantly different ($p<0.05$). There was no significant difference between treatments for grain yield; values in parentheses are standard error of means.

While there were no significant differences in yield between the treatments, grain protein and oil content were significantly influenced by treatment (Table 3). Protein ranged from 46.3–48.2 per cent, with the highest protein observed in the treatments that increased soil pH and provided additional nutrients (including the reactive phosphate rock, lucerne pellet, magnesium silicate and lime-with-phosphorus treatments).

While significant differences in oil content occurred due to treatment, no clear causation pattern was apparent, with oil content ranging from 40.5 per cent in the high rate of deep reactive rock phosphate treatment to 42.8 per cent in the deep phosphorus treatment. There were no significant differences in glucosinolate concentrations of grain due to treatment.

Conclusion

The inorganic soil amendments applied during 2017 continued to influence soil pH during 2019 and, via a strongly defined relationship, aluminium percentage. The lucerne pellet organic amendment appears to no longer be increasing soil pH, however still seems to be moderately effective at decreasing aluminium percentage at a given pH.

While no yield differences were recorded across treatments in the 2019 canola crop, perhaps due to poor crop establishment caused by a storm event soon after sowing, differences in grain quality still existed. Increased grain protein was observed in treatments that ameliorated the acidic conditions in the subsurface soil and also provided additional nutrition.

Although seasonal effects may impact yield, the soil improvements from inorganic amendments persist, and may be seen as a long-term benefit of the financial expense of the amelioration. Monitoring of future yield is required to capture this long-term benefit.

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