Future proofing agricultural production through effective acidic soils management

KEY FINDINGS

- Surface-applied lime that is only incorporated by the sowing operation has limited effect on increasing pH and decreasing exchangeable aluminium percent below the surface 0–5 cm layer.
- Incorporation of lime provides a head-start in ameliorating subsurface acidity and increasing pH to the depth of mixing.
- There appears to be no benefit in multiple incorporation passes with tillage implements
- The soil/lime mixing capability of tillage implement is a key attribute

Project title

Future proofing agricultural production through effective acidic soils management

Project code 4-CS70YK0

Project partners

FarmLink, NSW DPI, ANU, CWFS, Incitec Pivot Fertilisers, Holbrook Landcare Network.

Funding partner

Australian Government National Landcare Programme

Trial Site Locations TAIC (Temora), Grenfell

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INTRODUCTION

Producer and advisor surveys indicate that current approaches to managing soil acidity are based on research and guidelines from the 1990s that were developed under very different and less productive farming systems than in operation today. Most fertiliser, lime and crop selection decisions are guided by soil sample analyses collected at traditional depths of 0–10 cm. Depending on the crop or pasture sequence, the common trigger to apply lime is when soil pH_{Ca} is around 4.5–4.8. It is applied at minimal rates to remove toxic aluminium (target pH_{Ca} 5–5.2).

These traditionally reactive approaches and a failure to monitor the effectiveness of acid soil management programs are responsible for widespread, undetected subsurface acidification in marginally acidic soils; even in those with a long history of soil testing and lime application (Burns and Norton 2018). Recent studies challenge the short-term focus of current acid soil management programs:

- Li et al. (2019) recommended revising pH targets and re-liming intervals in order to address subsurface acidification, proposing soil maintenance pHCa above 5.5 in the 0–10 cm surface layer to gradually increase subsurface pH.
- Condon et al. (2020) highlighted inadequacies of current acid soil management programs and reinforced the need for a shift from mitigating soil acidity to prevention, particularly in zero tillage farming systems.
- Conyers et al. (2020) concluded that ongoing reaction of limestone and reacidification processes influenced soil pH and that 'the slow but measurable improvement in subsurface acidity, and the sustained residual value to grain yield' required a long-term approach to amelioration efforts to manage and prevent subsurface acidification.

This paper reports preliminary soil test results from two large-scale, replicated field experiments established in March 2020. The sites near Temora and Grenfell were designed to monitor long-term changes in soil chemical properties and:

1. investigate the optimal rate of lime and application methods to prevent subsurface acidification via incorporation or enhanced movement of the lime effect
2. identify the longevity of the effect of lime application and the acidification rate of current farming practices.

SITE DETAILS

Location/s

- Site 1: Temora site – approximately 5km North of Temora, NSW
- Site 2: Grenfell site – approximately 21km Southeast of Grenfell, NSW

Soil type

- Site 1: Temora; Red Chromosol; soil pH_{Ca} range of 4.7-5.2 in subsurface layers (5–15 cm)
- Site 2: Grenfell; Red Chromosol; soil pH_{Ca} range of 4.2-4.7 in subsurface layers (5–15 cm)

At the commencement of the trial in 2020 the Temora site was moderately to slightly acidic (pH_{Ca} 4.7-5.5 down to 20cm). There was no major pH stratification present at this site. In comparison, the Grenfell site was severely acidic and there was significant stratified soil pH and subsurface acidification (stratified acidification at 5-15cm of pH_{Ca} 4.2-4.7).

Both sites do not have a significant lime history. The Temora site was selected because it does not have a major acidity problem yet and therefore is an ideal site to test the effectiveness of proactive management to prevent formation of acidic constraints to plant production. The Grenfell site does have an acidity problem with severely acidic subsurface layers which need amelioration. This site was chosen as it represents a large area of cropping land that requires immediate amelioration.

Soil sampling

Soil samples were collected 13 months and 25 months after lime application for comprehensive chemical analysis. Soil cores were divided into 2.5 cm increments within depths of 0–20 cm, to detect change in soil pH and movement of alkali down the soil profile. The effectiveness of each lime treatment is gauged by the increase in soil pH and decrease in exchangeable aluminium percent (Al_{ex}%) compared with the control (nil lime).

Previous crops

- Site 1: Temora; Wheat (Vixen) 2020, Barley (Spartacus) 2021,
- Site 2: Grenfell; Canola (45Y90CL) 2020, Wheat (Coolah) 2021,

Rainfall (2020)

- Site 1: Temora; 686mm
- Site 2: Grenfell; 763mm

Rainfall (2021)

- Site 1: Temora; 776mm
- Site 2: Grenfell; 942mm

TREATMENTS

Large-scale, replicated field sites were established in early 2020 to monitor change soil pH and Al%, from 0-30cm, under high input, mixed farming systems. A range of lime and incorporation treatments were applied in March 2020 (Temora, Table 1) and April 2020 (Grenfell, Table 2). Lime (NV= >95%, >70% particles finer than 250 um) sourced from Westlime Parkes and was applied using a direct drop lime spreader at Temora and a commercial agricultural spreader at Grenfell. At Temora plot sizes were 85m long by 5.4 m wide and at Grenfell plots were 180m long by 9m wide. The Temora site had 6 treatments and 4 replications. The Grenfell site had 8 treatments and 4 replications.

Treatments were designed to answer the following questions raised by local growers and advisors:

- What is the optimal rate of lime and application methods to prevent and/or ameliorate subsurface acidification?
- Does incorporation increase the rate and depth of pH increase in the soil subsurface?

Table 1. Lime rates and incorporation treatments applied to large-scale field site at Temora.

Treatment ID	Incorporation treatment	Description	Site 1: Temora Rate of lime applied (t/ha)
1	Control	Nil lime, Not incorporated (NI)	0
2	Incorporation (Year 1 pre sowing)	Surface lime (target pH_{Ca}>5.5 at 0-20cm depth) incorporated with offset	4
3	No incorporation	Surface lime (target pH_{Ca}>5.5 at 0-20cm depth)	4
4	No incorporation	Surface lime (target pH_{Ca}>5 at 0-20cm depth)	1
5	Incorporated stubble after year 1 harvest	Surface lime (pH_{Ca}>5.5 at 0-20cm depth) + Organic matter (stubble), incorporated with offset	4
6	Incorporation x 2 (Year 1 pre sowing)	Lime (pH_{Ca}>5.5 at 0-20cm depth) incorporated with offset twice	4

TREATMENTS

Table 2. Lime rates and incorporation treatments applied to large-scale field site at Grenfell.

Treatment ID	Incorporation treatment	Description	Site 2: Grenfell Rate of lime applied (t/ha)
1	Control	Nil lime, Not incorporated (NI)	0
2	No incorporation	Surface lime (target pH_{Ca}>5.5 at 0-20cm depth), incorporated by sowing	7
3	Incorporation (Year 1 pre sowing)	No lime, incorporated with offset disc	0
4	Incorporation (Year 1 pre sowing)	Surface lime (target pH_{Ca}>5.5 at 0-20cm depth), incorporated with offset disc	7
5	Incorporation (Year 1 pre sowing)	No lime, incorporated with speed tiller	0
6	Incorporation (Year 1 pre sowing)	Surface lime (target pH_{Ca}>5.5 at 0-20cm depth), incorporated with speed tiller	7
7	Incorporation (Year 1 pre sowing)	No lime, incorporated with speed chisel	0
8	Incorporation (Year 1 pre sowing)	Surface lime (target pH_{Ca}>5.5 at 0-20cm depth), incorporated with speed chisel	7

Lime application dates and incorporation method

- Site 1: Temora; Limed on 5 May 2020; incorporation to estimated depth of 10 cm with offset discs.
- Site 2: Grenfell; Limed on 31 March 2020; incorporation to estimated depth of 10 cm for speed tiller, 15 cm for offset discs and 25 cm for speed chisel.

Seasonal conditions

Conditions were very dry in 2019 and into early 2020. This dry period ended with increased rainfall from February/March onwards at both sites. The Temora site received 63mm in February, 97mm in March and 97mm in April before an incorporation event on 15 May 2020. This high rainfall provided ideal incorporation conditions at the Temora site and the above average rainfall continued for the majority of 2020, 2021 and 2022.

The Grenfell site received 34mm in February and 82mm in March before the incorporation event on the 31 March 2020. This rainfall at the Grenfell site resulted in ideal incorporation conditions. This above average rainfall also continued for the majority of 2020, 2021 and 2022.

RESULTS AND DISCUSSION

Soil test results

The Temora and Grenfell sites received average to above average rainfall in their first three years (2020, 2021 and 2022). This rainfall would have benefited the reactivity and neutralisation rate of the applied lime.

The trials have been cropped each year so the pH results shown are the combined effect of neutralisation from lime and any acidification from 3 years of production.

SITE 1: TEMORA

By the 3rd year of the trial, lime application to achieve pH_{Ca} 5 in the surface 10 cm significantly increased soil pH relative to the untreated control in the surface 5 cm only. The standard practice of targeting near pH_{Ca} 5 is shown to be ineffective at increasing pH in the subsurface soil. Surface application of lime at rates targeting pH_{Ca} >5.5 resulted in significant pH increase to 10 cm.

The cultivation of the offset discs was measured down to a depth of approximately 10 cm at the time of lime incorporation. The year 3 soil results indicated that incorporation with offsets caused significant increase in pH, relative to the control, to a depth of 12.5 cm. In the surface layer of 0-2.5 cm the incorporated lime treatments was less than the non-incorporated surface applied lime treatment, as more lime would have been mixed to lower depths by the action of the offset disc.

The incorporation of lime applied to target pH_{Ca} >5.5 significantly increased soil pH in the 5 to 12.5 cm layers relative to surface application of the same rate of lime. Incorporation provided a head-start of the movement of the liming effect of the applied lime.

Incorporation with two passes of the offset disc increased the effective depth of pH increase to 15 cm relative to the control but did not result in any differences in soil pH compared to a single incorporation pass in any layer. This is an important finding; effective incorporation in a single pass saves fuel, time and presumably provides less damage to soil structure than two passes.

Given that the profile did not have severe acidity and had relatively low proportions of exchangeable aluminium, surface application of lime targeting pH >5.5 would be an effective practice to proactively manage soil acidification in this soil. The head-start that incorporation provides is not vital to production if the soil does not have severe acidic subsurface layers present. That is, surface application with lime targeting pH_{Ca} >5.5 and adequate time may serve to stop acidic subsurface layers forming. However, it is imperative that the depth and severity of acidity is determined by soil testing pH and Al% in 5 cm intervals to a depth of 20 cm before determining the best strategy for proactive management of acidity.

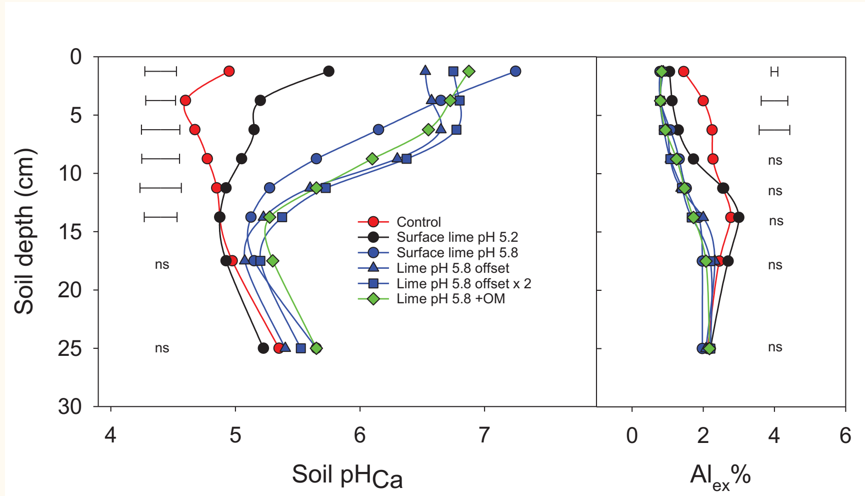

Figure 1. Soil pH_{Ca} and exchangeable aluminium percentage (Al_{ex}%) from soil sampled pre-sowing in 2023 at the Temora site. Treatments were applied pre-sowing in 2020 and included various liming strategies. Horizontal bars indicate least significant differences (lsd, p<0.05), ns indicates no significant difference between treatments.

RESULTS AND DISCUSSION

Soil test results

SITE 2: GRENFELL

Three years after treatment application there were no significant difference in the soil pH profiles of treatments that did not receive lime, regardless of the type of cultivation conducted. Surface applied lime at a rate to achieve pH_{Ca} >5.5 significantly increased soil pH, relative to the control, however this effect was only significant in the surface 5 cm.

The incorporation of that rate of lime with any implement decreased the soil pH in the 0-2.5 cm layer compared to surface applied lime treatment due to mixing of lime to lower depths. There was no significant difference in the pH profiles created by lime incorporation with the speedtiller, offset disc or speedchisel. All implements significantly increased pH and decreased Al% to a depth of 12.5 cm compared to the untreated control.

This trial site showed the benefits of targeting pH>5.5 with lime rates higher than traditional application rates, in this case 7t lime/ha. The type of implement used to incorporate lime had minor influence on the depth or extent of amelioration with incorporation effectively doubling the depth of amelioration compared to surface applied lime.

This site has an acid throttle at about 5-20cm and this can be easily seen in the untreated control. While incorporating lime increased soil pH in the surface 12.5 cm, after 3 years the acidic subsurface layer remains below that depth. Therefore, the acid throttle remains to threaten production in suboptimal years (for example, with poor autumn breaks) or when acid sensitive plants are grown.

It was expected that the speedchisel would have been more effective at ameliorating deeper acidity than the speedtiller or offset disc due to the greater depth of tillage of the speedchisel (25 cm) compared to the speedtiller and offset (10cm). Whilst, there is evidence of the speedchisel mixing soil from lower in the profile, the mixing effect of all implements in the surface 10cm appear similar. Soil mixing is a key attribute of any incorporation machine and not just the depth of tillage.

It is important to note that there was no significant difference between the type of tillage machinery used in regard to increasing soil pH, at all depths.

The Grenfell site demonstrates the benefit of applying lime to target pH_{Ca} >5.5 and incorporating that lime to gain a head-start in the amelioration of subsurface acidity. Even with incorporation, an acid throttle remains, although due to maintaining pH_{Ca} >5.5 the expected enhanced movement of the lime effect below the depth of incorporation will ameliorate the acid constraint in the next few years.

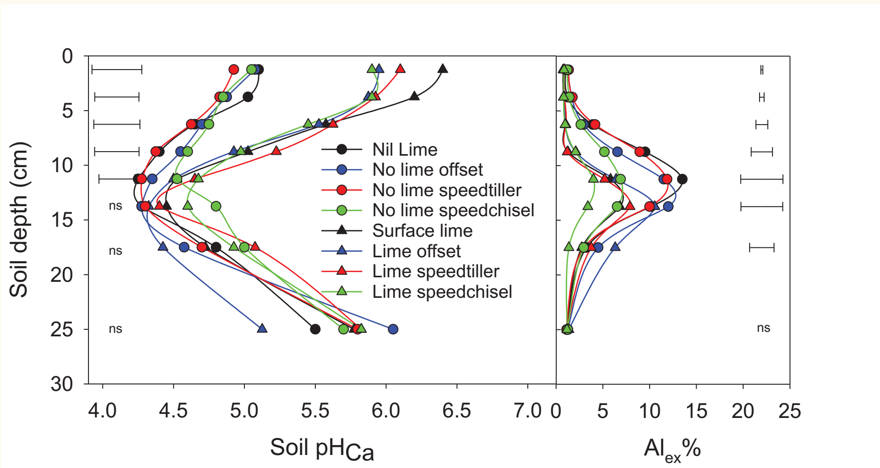

Figure 2. Soil pH_{Ca} and exchangeable aluminium percentage (Al_{ex}%) from soil sampled pre-sowing in 2023 at the Grenfell site. Treatments were applied pre-sowing in 2020 and included lime application (0 and 7 t/ha) with incorporation via different implements or surface application only. Horizontal bars indicate least significant differences (lsd, $p<0.05$), ns indicates no significant difference between treatments.

SUMMARY

Preliminary soil test results indicated that across all sites and treatments, targeting pH_{Ca} >5.5 results in greater depth of lime benefit and subsequent pH increase. When lime was incorporated, the magnitude of pH and Al_{ex}% change was accelerated to the depth of incorporation, or deeper. When lime was not incorporated the depth of lime effect increased with the rate of lime application, but even then, the greatest change in pH and Al_{ex}% was concentrated in the 0–5 cm surface layer.

Initial results indicate that:

- A target pH_{Ca} >5.5 in the 0–10 cm layers enhances amelioration of subsurface acidity
- Incorporation will increase the depth to which pH increases.
- There appears no benefit in multiple passes of incorporation machinery
- There appears to be minimal difference between types of tillage machinery.
- Effective soil/lime mixing is a key attribute when selecting tillage equipment rather than depth alone.
- Soil sampling in 5 cm intervals enables the depth and severity of acidity to be understood allowing targeted liming/incorporation strategies to be determined.

Average to above average rainfall at all sites following lime application aided lime reaction. The response to lime treatments in marginal years/seasons is yet to be investigated. Further monitoring of these sites is required to assess the role for more frequently applied, lower rates of lime in zero tillage systems, the residual value of lime and potential to prevent subsurface acidification through early intervention on marginally acidic sites.

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Acknowledgements

This experiment was part of the 'Future proofing the soils of Southern and central NSW', project, funded by the Australian Government National Landcare Program. The partner organisations involved in this project include: FarmLink Research, Holbrook Landcare, Central West Farming Systems, NSW Department of Primary Industries, Australian National University and Incitec Pivot.

The contribution by participating landowners is greatly appreciated.

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