Future proofing agricultural production through effective acid soil management

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Introduction

Soil acidification is a natural weathering process that is accelerated under agricultural systems. For a given soil, the more productive a system, the greater the acidification rate. To prevent soil degradation and ensure the long-term sustainability and productivity of soils supporting the most productive grazing systems in the mixed farming zone of Central and Southern NSW soil condition must be monitored and acid soil management programs adjusted accordingly.

Soil test results from commercial paddocks and grower and advisor surveys of current practices identify opportunities to improve the efficiencies of acid soil management and prevent subsurface acidification. This needs significant changes in attitude and practices: revised soil sampling protocols, short- and medium-term monitoring of soil pH change to assess the effectiveness of lime investments, a reset of pH triggers to lime and pH targets after liming.

Contents

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Identifying subsurface acidity

- An ‘acid throttle’ at 5 to 15 cm (Fig. 1) indicates that most current lime rates are insufficient to neutralise acidity at 5 to10 cm, resulting in unchecked subsurface acidification.
- Under minimum tillage systems topdressed lime, which is only incorporated by sowing, results in elevated pH in the 0-5 cm layer but has limited effect in layers below 5 cm (Fig. 1).
- Soil samples collected at standard depths of 0-10 cm and 10-20 cm do not detect pH stratification or the depth and severity of acidity. For example, in Figure 1, soil pH for sampling depth of 0-10cm for Group 1 and Group 2 would return pH_{Ca} 4.6 and 5.3, respectively.
- A spade or soil corer and a soil pH kit (available from most rural or garden/hardware suppliers) provide a quick and convenient way to check for the presence of acidic subsurface layers. E.g. soil pH is indicated by chemical dye and indicator powder and checked against a colour card in the Manutec® soil pH kit (Fig.2). Follow up with more detailed sampling and analysis from an accredited laboratory to guide management decisions.

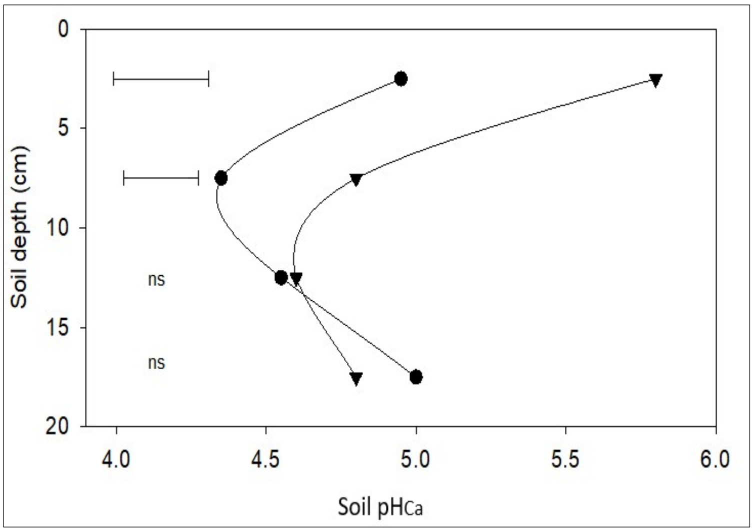

Figure 1. Central and southern NSW soil pH profiles (2015-2019): Group 1 (●; n=15) limed more than 5 years ago, Group 2 (▼; n=33) limed in the last 5 years. Ineffective lime incorporation under minimum tillage systems has caused elevated pH in the shallow surface layer (0-5 cm). Lime application has had limited effect below 5 cm.

Figure 2. Canola plants and soil samples from the field site at Morven: April 2020, 6 months after lime application and 7 weeks post sowing. Both plants are from plots treated with lime at a rate of 4 t/ha, either incorporated with disc harrows (left), or topdressed (right). Improved root growth on the left indicates that the lime was mixed to a depth of at least 5 cm and confirmed by the purple colour on the surface soil layer in the soil probe on the Manutec® soil kit colour card (i.e. $pH_{Ca} > 6$). On the right, a narrow band of purple on the soil surface overlies a yellow layer (pH_{Ca} approx. 4.5), indicating that the topdressed lime was only mixed with narrow sowing points has had no effect below the soil surface.

New approaches to managing soil acidity

Surveys of producers and advisors indicate that current approaches to management of soil acidity are based on guidelines developed under very different and less productive farming systems in the 1990s. Detailed soil tests of actively managed commercial paddocks tell us that these practices are ineffective in ameliorating soil acidity or preventing subsurface acidification. Table 1 lists current approaches and practices, and management changes needed to ameliorate subsurface acidity and protect productive farming systems from ongoing acidification.

Table 1. Traditional approaches to acid soil management need updating to mitigate and prevent soil acidification in modern farming systems.

Current/traditional management practices	Changed management proposed
• Soil test results (i.e. pH, % Al) from samples collected at traditional sampling depth of 0-10 cm guide the decision to apply lime.	• Sample at 5cm intervals to a depth of 20 cm in order to detect the extent and depth of acidic subsurface layers.
• Lime* application is triggered when 0 – 10 cm soil pH_{Ca} is between 4.5-4.8 or when exchangeable aluminium approaches 5%. This prioritises lime application on about 39% of commercial paddocks surveyed in southern slopes and tableland of NSW that are constrained by acidic subsurface layers. • This is not detected with 0-10 cm sampling.	• Increase the critical pH that triggers lime application (pH_{Ca} 5.5). Monitor pH of all soils; don't ignore the most productive soils, which are at high risk of acidification. Implement amelioration efforts before subsurface pH reaches toxic levels and plants show toxicity symptoms and suffer production loss.
• The amount of lime applied is enough to raise pH in the 0-10 cm layer to about 5.2, i.e. sufficient to reduce % Al_{ex} to non-toxic levels.	• If subsurface acidity is detected, apply enough lime to increase 0 – 10 cm pH_{Ca} above 5.5. This will neutralise acidity in the surface soil and the lime benefit will gradually move down the profile and increase subsurface pH.
• Re-liming intervals are sporadic, guided by crop toxicity symptoms, soil test results or cropping/pasture programs.	• Monitor soil pH. If the aim is to increase subsurface pH, maintain 0-10 cm soil pH_{Ca} above 5.5 and relime before subsurface pH declines.
• Lime is surface applied and only incorporated by sowing.	• Strategic tillage to incorporate lime speeds up the lime reaction and increases the lime effect to the depth of cultivation.
• Lime is applied immediately before sowing sensitive species	• Delay sowing acid-sensitive species for at least 18 months after lime application to allow time for the lime to react and raise pH.

***NOTE:** Any reference to liming material in this report assumes the material is fine-grade, high quality lime with neutralising value (NV) > 95 and fine particle (90% passes through a 150 µm sieve).

Recommendations when subsurface acidity is present

- Be proactive:
  - monitor subsurface layers for pH decline
  - don't wait until production declines and symptoms of soil acidity appear.
- Review liming triggers and pH targets:
  - **maintain pH_{Ca} above 5.5** in the 0-10 cm surface layer in order to increase soil pH_{Ca} in the layers below 10 cm. This will deliver enough alkalinity to neutralise acidity in the 0-10 cm layer and provide excess alkali to gradually increase pH of the subsurface layers (Li et al 2019).
  - **set pH_{Ca} 5.5 as the trigger to relime**.

- Early intervention to prevent development of acidic subsurface layers makes financial and practical sense. E.g. the amount of lime required to lift soil pH_{Ca} from 5.3 to 5.8 is less than the amount required to go from 4.5 to 5.0
- Don't forget to monitor soil acidity status of the highly productive soils. These are unlikely to be prioritised for liming, despite having the highest acidification rates. Decline in production from these will be very gradual and hard to detect as subsurface layers acidify.
- Incorporate lime to fast-track subsurface amelioration. Effective incorporation increases the depth of the lime effect, speeds up the lime reaction and accelerates pH increase in subsurface layers.
- **Do not use high rates of lime if it is not to be incorporated**. Lime left on the soil surface will elevate pH in the shallow surface layer and reduce the solubility of the applied lime, leaving it unreacted on the surface and exposed to wind and water erosion.
- If incorporation is planned, be aware of erosion risks. Cultivate on the contour and apply rates of lime that justify the expense of incorporation and the erosion risk.
- If incorporation is not an option soil management programs should shift to early intervention strategies to manage ongoing subsurface acidification, because the alkali from surface-applied lime moves very slowly down the profile – *i.e. see Toogong trial on page 7*.
- Delay sowing acid-sensitive species for at least 18 months after lime application to allow time for the lime to react and raise pH. Dry conditions will slow lime reaction.
- **Caution needed the first season after cultivation:** Cultivation creates a 'fluffy' seedbed:
  - Check seed placement. If depth control is likely to be an issue, avoid sowing small seeded plants such as canola and pasture species in the first season after cultivation
  - Trafficability can be an issue on cultivated soils in wet seasons. This could impact weed management and grazing options. Reconsider sowing grazing crops in the first season following cultivation.

Field sites: Lime rates and incorporation treatments

A series of large-scale (2 ha), replicated field sites were established by NSW DPI in late 2019 and early 2020 with project partners Grassland Society of NSW and Holbrook Landcare Network, and supported by the National Landcare Program. Sites at Lyndhurst, Morven and Toogong were established to monitor medium- and long-term change in soil properties to depth (30 cm), under high input, mixed farming systems. A range of lime and incorporation treatments (Table 2) were applied in December 2019 (Morven) and February 2020 (Lyndhurst and Toogong). Lime was applied using a direct drop lime spreader at all sites; sourced from NSW crushers, with a neutralising value of 98 and fine particle size (90% passes through a 150 µm sieve).

The lime rate and incorporation treatments applied at each site, explained below and summarised in Table 2, were designed to answer the following questions from local growers and advisors:

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

Treatment 1 (Control): Nil lime, Not Incorporated (NI)

Treatments 2 (NI) **and 3** (Incorporated - Inc): Maintain pH_{Ca} of the 0-10 cm layer above 5.5, with pH_{Ca} of 5.5 as the trigger to relime.

Treatments 4 (NI) **and 5** (Inc): Traditional approach - target pH_{Ca} 5.2 in 0-10 cm layer, with trigger to relime when pH_{Ca} decrease to < 5.0

Treatment 6 (NI): Low initial rate of lime followed by more frequent applications, compared with Treatment 2 & 3; pH_{Ca} of 5.5 in 0 – 5 cm layer as the trigger to relime. *When lime incorporation is not an option, can subsurface pH be increased by maintaining 0-5 cm pH_{Ca} >5.5?*

Treatment 7 (Inc): 'Once-in-a generation' treatment. *When incorporation is an option will a high lime rate and one-off incorporation ameliorate and prevent subsurface acidity, while minimising application and incorporation costs, and limiting erosion risk to a single event.* Does this treatment:

- ameliorate and prevent subsurface acidification in the long-term
- induce nutrient deficiencies?
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Table 2. Lime rates and incorporation treatments applied to large-scale field sites at Lyndhurst, Morven, and Toogong sites.

		Lyndhurst *Soil pH$_{Ca}$ range in 5-15 cm subsurface layers: 3.9 – 4.1; Incorporated with Horsch® Tiger*	**Morven** *Soil pH$_{Ca}$ range in 5-15 cm subsurface layers: 4.0-4.3; Incorporated with disc harrows*	**Toogong** *Soil pH$_{Ca}$ in 5-15 cm subsurface layers: 4.8; Incorporated with disc harrows*
Treatments		**Rate of lime applied (t/ha)***		
Control – Nil lime	Not incorporated	0	0	0
2 & 3. Increased pH target in 0-10cm: pH$_{Ca}$ >5.5 (5.9) Trigger for re-application: 0-10 cm pH$_{Ca}$ decreases to 5.5	**2.** Not incorporated **3.** Incorporated	5.9	4	2.8
4 & 5. Traditional pH target 0-10cm: pH$_{Ca}$ >5.2 Trigger for re-application: 0-10 cm pH$_{Ca}$ decreases to < 5.0	**4.** Not incorporated **5.** Incorporated	4.7	3	1
6. Maintain target in 0-5cm at pH$_{Ca}$ >5.5 Trigger for re-application: 0-5cm pH$_{Ca}$ decreases to 5.5	Not incorporated	2.9	2	1.4
7. 'Once-in-a–Generation'	Incorporated	7	6	3.8
Time lag between lime application and soil sampling (months) and rainfall in that period (in brackets)		11 (1030 mm)	14 (620 mm)	10 (730 mm)

* Historic guidelines recommend splitting applications of more than 4 t/ha to avoid potential nutrient deficiency symptoms (Table 11; Agfact AC.19).

All sites were sown to crop in 2020: dual-purpose canola at Morven and Toogong; dual-purpose wheat at Lyndhurst. They are scheduled to be sown to pasture in 2021 or 2022.

The soil pH was severely acidic (pH$_{Ca}$ < 4.5) to 30 cm depth at Lyndhurst and to 20 cm at Morven. Neither site had a history of lime application but had been prioritised for lime application.
In comparison, the Toogong site returned soil pH$_{Ca}$ of 5.0 collected from a sampling depth of 0-10 cm, so would not be a high priority for liming based on current acid soil management principles. However, sampling in 5 cm increments at the Toogong site indicated stratified soil pH and subsurface acidification: the 0-5 cm surface pH$_{Ca}$ is 5.1, but decreases to 4.8 in the 5-15 cm subsurface layers, increasing to 5.2 at 15-20 cm and 6.0 in layers below 20 cm.

Toogong is an ideal site to test the effectiveness of early intervention in preventing development of acidic subsurface layers over the long term. It is typical of the more productive soil types of the region (Red Kandosol) with no observed chemical or physical soil constraints limiting productivity. Acidification rates are likely to be high on the high input/high output mixed farming systems supported but are not effectively managed under traditional liming programs.

Response to lime treatments

Soil samples were collected 10 to 14 months after lime application for detailed chemical analysis. Soil cores were divided into 2.5 cm increments within depths of 0-20 cm and into 5 cm increments from 20-30 cm, to monitor movement of alkali down the soil profile and influence on pH and.

Only the results of soil pH and exchangeable aluminium changes from the first year of sampling are reported here. 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).

Despite significant rainfall at all sites in 2020, a considerable proportion of the applied lime would not have reacted (Conyers *et al.* 2020). Therefore, the soil test results presented should be used as an early indication of the relative effectiveness of the lime and incorporation treatments. We expect that pH will continue to increase until most of the lime has dissolved. Eventually ongoing acidification will outstrip the neutralising processes being driven by alkali released from the unreacted lime. When this occurs, the soil will reacidify and pH decrease.

Lyndhurst

Depth and magnitude of pH and Al_{ex}% change was greatest where lime was incorporated, i.e. Treatments 3, 5 and 7. A Horsch® Tiger cultivator was used to incorporate lime and although soil was disturbed to a depth of about 20 cm, pH change indicates that the lime was only mixed to a depth of about 15 cm (Fig. 3). There was significant increase in soil pH for all incorporated treatments in all layers down to the 12.5 - 15 cm layer, compared with the Nil lime treatment, with the magnitude of change decreasing with depth.

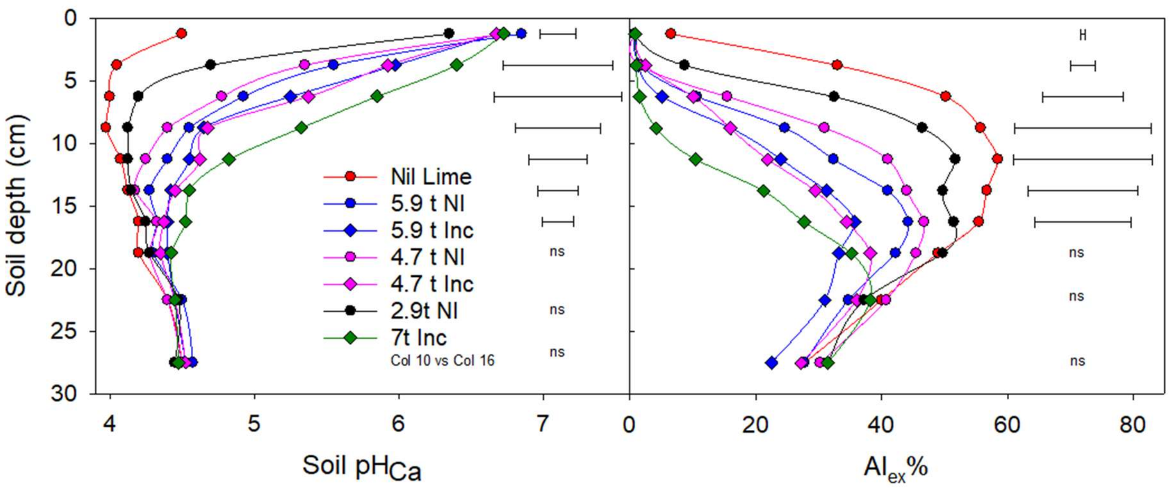

Figure 3. Soil pH increased and exchangeable aluminium percent (Al_{ex}%) decreased with lime application at Lyndhurst on the Central Tablelands of NSW. The depth of the lime effect and increase in pH and corresponding decrease in Al_{ex}% was greatest where lime was incorporated (Inc) compared with the topdressed, not incorporated treatments (NI). Horizontal bars represent l.s.d. (P<0.05); ns = no significant difference.

In comparison, lime rate influenced the depth of significant pH change for the unincorporated lime treatments (2, 4 and 6). Soil pH change indicates that the lime effect only reached the 7.5-10 cm layer for Treatment 2 (target pH_{Ca} > 5.5: 5.9 t/ha lime), significantly increasing pH. Treatment 4 (target pH_{Ca} > 5.2; 4.7 t/ha lime) did not significantly increase pH below the 5.0-7.5 cm layer.

The treatment that closely reflects industry practice is Treatment 6: i.e. lime was topdressed and incorporated by sowing (2.9 t/ha NI: target pH_{Ca} >5.5 in 0 – 5 cm) did not significantly increase pH below the surface 0-2.5 cm layer.

Figure 3 shows significant effect of lime application on the Al_{ex}% profile below the depth of change in soil pH. The decrease in Al_{ex}% was significant for all incorporated treatments to a depth of 15.0 – 17.5 cm. However, only the 'once-in-a-generation' treatment (7 t/ha of lime) increased pH significantly to that depth. This indicates that some of the added alkali from lime reacted with Al_{ex} and that alkali is no longer in solution to increase pH. That is, the reaction of Al_{ex} to forms not available to plants buffers the pH change due to lime.

For the unincorporated lime treatments, the higher the lime rate, the deeper the effect on Al_{ex}%, with a significant decrease down to 10.0 – 12.5 cm for 5.9 t/ha (NI: target pH_{Ca} >5.5), to 7.5 – 10.0 cm for 4.7 t/ha (NI: target pH_{Ca} >5.2) and to 5.0 – 7.5 cm for 2.9 t/ha of lime. As was the case for change in soil pH, the magnitude of lime effect on Al_{ex}% declined with depth for all treatments.

Morven

Disc harrows incorporated lime at the Morven site. This was much less effective in mixing lime to depth than the aggressive mixing by the Horsch® Tiger. However, while soil was estimated to have been disturbed to a depth of about 10 cm, soil tests for Al_{ex}% indicate a significant lime effect in layers from 0 – 12.5 cm for all lime treatments (Fig. 4).

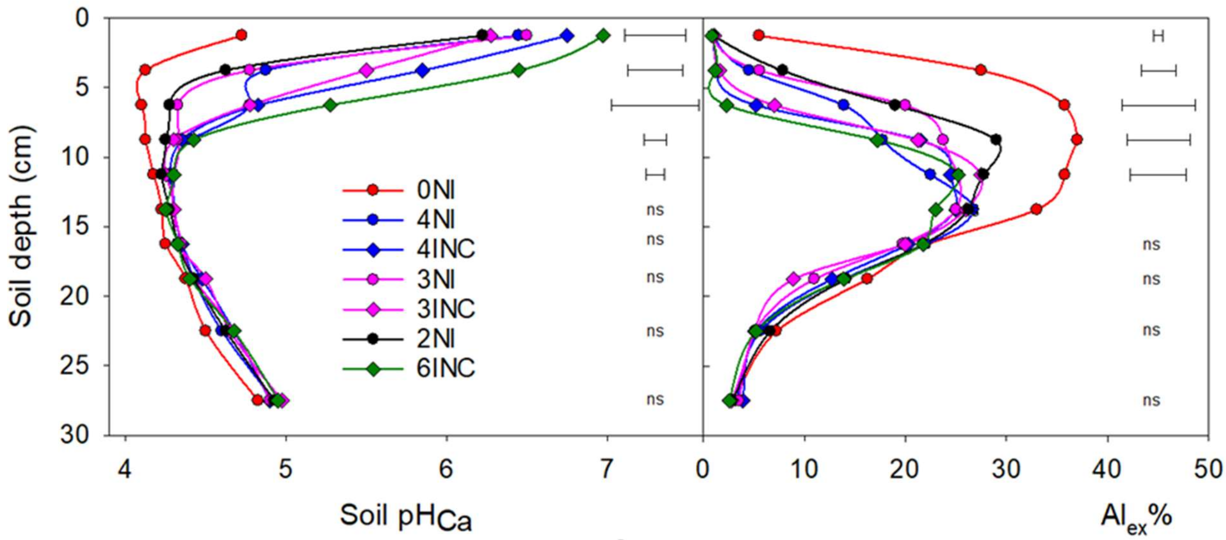

Figure 4. Soil pH increased and exchangeable aluminium percent (Al_{ex}%) decreased with lime application at Morven on the Southern Slopes of NSW. The depth of the lime effect and increase in pH and corresponding decrease in Al_{ex}% was greatest where lime was incorporated. Horizontal bars represent l.s.d. (P<0.05); ns = no significant difference.

There was a significant change in pH down the profile to a depth of 10 – 12.5 cm for all incorporated lime treatments but only at the highest rate of unincorporated lime applications (4 t/ha NI: target pH_{Ca} >5.5). Where lime was not incorporated, change in pH relative to the Nil lime treatment, indicates that the lime effect is concentrated in the surface 0-2.5 cm with a small change in pH at 2.5 – 5 cm. There was no significant change in pH below 5 cm at the lower unincorporated lime rates (3 t/ha NI: target pH_{Ca} >5.2; and 2 t/ha NI: target 0 – 5 cm pH_{Ca} >5.5).

The change in Al_{ex}% mirrored pH change. Lime incorporation produced a greater and more uniform decrease in Al_{ex}% down the profile, particularly in the 2.5 – 7.5 cm layers.

Toogong

The Toogong site puts a spotlight on the moderately acidic soils that are usually not included in discussions about acid soil management. Liming programs are sporadic or non-existent on these productive soils, although they are likely to have high acidification rates. Medium to long-term soil data collected from this site will provide valuable information on the production, sustainability and financial benefits of preventing subsurface acidification through early intervention.

There was a small, but significant response to lime rate and incorporation treatments at the Toogong site (Fig. 5). The unincorporated treatments and incorporated treatment 5 (1 t/ha Inc: target pH_{Ca} >5.2) did not change pH and Al_{ex}% below 5 cm.

Treatments 3 and 7, i.e. incorporated lime applied at rates to achieve a target pH_{Ca} > 5.5 (2.8 and 3.8 t/ha), produced the greatest change in pH and Al_{ex}% in the layers from 0-7.5 cm.

We anticipate that differences between treatments will develop in the medium to long term.

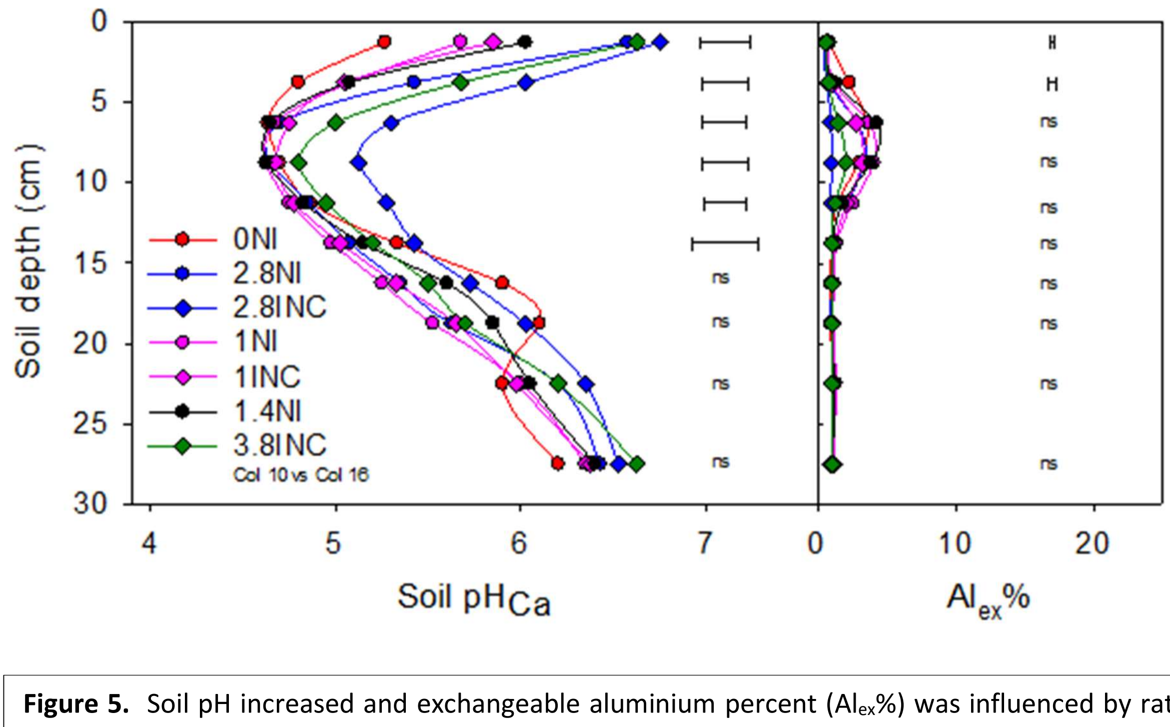

Figure 5. Soil pH increased and exchangeable aluminium percent (Al_{ex}%) was influenced by rate of lime and application methods at Toogong on the Central Slopes of NSW.

Summary

One year after lime application initial soil test results across all sites and treatments indicate that, targeting pH_{Ca} >5.5 results in a deeper lime effect. Lime incorporation increased in pH and reduced Al_{ex}% to the depth of incorporation, and occasionally deeper. When lime was not incorporated the depth of lime effect increased with rate of lime application, but even then, greatest change in pH and Al_{ex}% was concentrated in the 0 – 5 cm surface layer.

At the Lyndhurst and Morven sites unincorporated lime applied at rates of 2.9 and 2.0 t/ha, respectively, approximate traditional practices, i.e. unincorporated lime applied at rates of 2 – 2.5 t/ha and a pH_{Ca} target of 5.2. These produced limited change in pH or Al_{ex}%.

Initial results indicate that:

- a target pH_{Ca} > 5.5 in the 0 – 10 cm layers is needed to influence subsurface acidity
- incorporation will accelerate the lime reaction and increase the depth of the lime effect

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.

Further reading

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YouTube videos:
Accurate soil sampling to 20cm in 5cm intervals (Using soil corers): https://youtu.be/3KiS2P09KuY

A rapid check for subsurface acidity in the field (Using a soil probe): https://www.youtube.com/watch?v=01BQbHhEh8o&t=3s