Managing acidity in pasture systems

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Abstract: *Soil acidity has long been understood to be a problem in south-eastern Australia. Acidic subsurface layers present in pH stratified soil have been identified to be the major cause of decreased production of pasture legumes and reduced performance of acid-sensitive species. Consequently, pH stratification has negative impacts on grazing and mixed farming enterprises in southern NSW. Although liming remains the best method to manage acidic soil, old practices of low pH targets (pH_{Ca} 5.0), inadequate application rates and no or ineffective incorporation have resulted in continued acidification. Regular monitoring in smaller depth increments (5 cm), maintaining higher pH targets (pH_{Ca} 5.8–6.0) and calculation of lime rate requirements that account for application method are required to slow or reverse soil degradation by subsurface acidification. Liming to pH_{Ca} 5.8–6.0 facilitates movement of the effect of liming to lower soil layers with time. If higher pH is not maintained in the topsoil, the acidification of subsurface soils will extend further into the profile and may require more expensive operations that mechanically place amendments deep in the soil. Monitoring and proactive, preventative management of topsoil pH with lime addition remains the most cost-effective solution for growers.*

Key words: lime, acidity

Introduction

Extensive livestock systems form a central component of agricultural production in New South Wales (NSW), underpinning beef, sheep meat and wool enterprises across the tablelands, slopes and mixed-farming regions. Many of these systems have intensified over the last 40 years with more legume production, fertiliser use and increased stocking rates, resulting in substantial gains in productivity but also accelerated soil degradation, particularly soil acidification (Conyers *et al.* 2011; NSW DPI 2021).

Soil acidity is now recognised as one of the most widespread and economically significant soil constraints in NSW, with both surface and subsurface acidity limiting pasture productivity and persistence (Slattery *et al.* 1999; Condon *et al.* 2020). Despite widespread lime use in some areas, pasture responses have often been inconsistent, highlighting the limitations of traditional acid soil management approaches (Hayes *et al.* 2019). Surveys indicate that approximately 40−50% of agricultural soils in NSW exhibit subsurface acidity that can constrain root growth despite acceptable surface (0-10 cm) pH values (Slattery *et al.* 1999; Condon *et al.* 2020).

The economic cost of soil acidity to pasture-based systems includes reduced dry-matter production, lower legume content, diminished nitrogen fixation and reduced carrying capacity (Brennan and Goulding 2018). In grazing systems, these constraints translate directly into lower livestock performance and increased production risk, particularly in dry seasons (Conyers *et al.* 2011).

Acidification in pasture systems is unavoidable

Food and fibre production is acidifying. The use of ammonium-based fertilisers (MAP, DAP and urea) will always cause acidity within the soil profile, even if all the nitrogen is taken up by plants (Condon *et al.* 2004). Legume based pastures will also increase the nitrogen content in the soil and add to acidification (Helyar and Porter 1989; Paul *et al.* 2003; Conyers *et al.* 2011). In addition to acidification due to nitrogen, the removal of plant and animal products exports alkali from the soil system, further contributing to acidification (Slattery *et al.* 1999). As plants take up nutrients, they excrete acid into the rootzone. This leaves the plant material alkaline and in a balanced system that alkalinity will return to the soil at the site of growth to neutralise the acidity that was formed. However, in agricultural systems we remove the alkali plant material either as cut hay, silage or when the plant is consumed by grazing animals and converted to meat or wool that is ultimately sold through the farm gate.

Hay and silage production accelerate this process due to the large quantities of biomass removed, while grazing systems recycle some nutrients via dung and urine but still experience net alkalinity loss over time (Conyers *et al.* 2011). It is worth considering the increased use of dual-purpose crops. They have both grazing and grain harvest alkali product removal within the same season and have therefore intensified production which, consequently, may accelerate acidification. Recent NSW research has demonstrated that acidification processes are strongly stratified within the soil profile (Condon *et al.* 2020; Li *et al.* 2019). Acidic layers commonly develop between 5 and 15 cm depth due to nitrogen transformations, root activity and fertiliser placement. Whilst acidification is unavoidable, it can be managed with the use of lime applied to the soil to reverse the acidification effect on soil pH.

Why acid soils impact production

Aluminium toxicity is the primary chemical constraint in most acidic pasture soils in NSW (Slattery *et al.* 1999; Condon *et al.* 2020). As soil pH ($CaCl_2$) declines below approximately 5.0, aluminium becomes increasingly soluble and toxic to plant roots, restricting root elongation and branching. Restricted root systems reduce access to nutrients and water, significantly impairing drought resilience and pasture persistence (Hayes *et al.* 2019). Aluminium toxicity often occurs in subsurface layers where it is not readily detected by standard soil tests (Condon *et al.* 2020).

Soil acidity also affects availability of other important nutrients. Phosphorus becomes increasingly bound to aluminium and iron oxides, reducing opportunity for plant uptake (Helyar *et al.* 1997). Molybdenum availability declines at low pH, impairing legume nodulation and nitrogen fixation (Slattery *et al.* 1999). Calcium and magnesium deficiencies may also develop due to leaching of these cations when excessive quantities of aluminium take up the nutrient retention capacity (cation exchange capacity) of the soil. These problems create the potential to use fertiliser to overcome deficiencies due to low pH, therefore locking producers into more fertiliser use to treat a symptom rather than fixing the underlying problem that is acidity.

Acid soils negatively affect soil biological activity, including rhizobia populations essential for legume productivity (Helyar and Porter 1989). The benefit of legumes in pasture systems is diminished if those legumes are not able to fix nitrogen from the atmosphere due to poor nodulation or depressed growth associated with low pH and high aluminium concentrations. Reduced biological function slows nutrient cycling and organic matter turnover, further limiting pasture performance. For example, in a replicated long term liming trial at Morven, NSW, significantly higher frequency of worm castings was observed on limed pastures compared to unlimed control plots. These worms exist high in the soil food web and are indicative of the impact of acidity on soil biology.

The chemical and biological impacts of acidity in pasture systems accumulate to reduce pasture dry-matter production, often gradually, making the constraint difficult to detect until severe (Brennan and Goulding 2018). Acid-sensitive species, including many productive perennial grasses and legumes decline, leading to pasture composition shifts towards less productive but more tolerant species (Li *et al.* 2019).

Subsurface acidity restricts rooting depth, reducing drought tolerance and increasing pasture failure in dry seasons (Condon *et al.* 2020). These changes directly reduce stocking rates and livestock production per hectare (Brennan and Li 2006).

Do I have an acidity problem?

Soil testing remains the best diagnostic tool to identify the presence of soil acidity. Traditional soil sampling methods involved sampling the 0–10 cm surface soil; however, it is now understood this will underestimate acidity in subsurface layers (Condon *et al.* 2020). Sampling in 5 cm depth increments (e.g. 0–5, 5–10, 10–15, 15–20 cm) is now recommended to accurately diagnose acidity and inform lime rate calculations (NSW DPI 2021; Condon *et al.* 2020).

Investigating the response of lime as a management tool

Agricultural lime neutralises soil acidity by consuming hydrogen ions and increasing soil pH, thereby reducing aluminium toxicity and improving nutrient availability (Helyar *et al.* 1997). However, lime is sparingly soluble and reacts only where soil acidity exists.

Traditional liming practices in NSW often involved adding lime to raise pH only to just above pH_{Ca} 5 to alleviate the effects of aluminium toxicity. Surface application of low lime rates (1–2.5 t/ha) at long intervals (8−10 years) was standard practice based loosely on rules of thumb. Research has shown that these rates are insufficient under modern, high-productivity pasture systems (Condon *et al.* 2020; Hayes *et al.* 2019). The surface-applied lime commonly raised pH in the 0−5 cm layer but had little effect on acidic subsurface strata (Li *et al.* 2019). For the liming effect to reach deeper into the soil, the lime either needs to be placed deeper via incorporation (tillage) or a higher surface pH (pH_{Ca} 5.8−6) is required for alkalinity to move downwards with water percolation (Condon *et al.* 2020). Therefore, targeting soil pH_{Ca} 6 in the surface layer to facilitate aluminium detoxification, prevent further subsurface acidification and allow alkali to move deeper is recommended (Li *et al.* 2019; Hayes *et al.* 2019). Reliming should occur proactively before pH declines to critical levels.

With support from the Grassland Society of NSW and MLA, NSW Department of Primary Industries (NSW DPI) created a network of field trials to investigate the effectiveness of targeting soil pH_{Ca} 5.8–6 with and without deep incorporation compared to traditional approaches of targeting pH_{Ca} 5.2. The agronomic benefit of approaches was measured via pasture composition and production. This paper reports findings from one trial conducted at Lyndhurst NSW.

Methods

A replicated field trial was established in 2020 near Lyndhurst, NSW (-33.700442, 149.045197). Seven lime treatments were applied to plots (75 m × 9 m) in a randomised block design with four replicates. Treatments included an untreated control, lime at 4.7 t/ha to achieve pH_{Ca} of 5.2 in the 0–10 cm either surface applied or deep incorporated, lime at 5.9 t/ha to achieve pH_{Ca} of 5.8 in the 0–10 cm either surface applied or deep incorporated, lime applied at 7 t/ha to achieve pH_{Ca} of 5.8 to 20 cm deep incorporated and 2.9 t/ha surface applied to achieve pH_{Ca} 5.8 in only the 0–5 cm layer (Table 1).

Table 1. Lime treatments at Lyndhurst.

Treatment	Lime rate (t/ha)	Comment
1. Control – Nil lime + Nil incorporation	0	
2. Ameliorated to maintain pH 5.8 in the 0–10 cm	5.8	Surface applied, 1 application (trigger for re-application @ 5.5 pH in the 0–10 cm layer)
3. Ameliorated to maintain pH 5.8 in the 0–10 cm	5.8	Surface applied and incorporated, 1 application (trigger for reliming @ 5.5 pH in 0–10 cm layer)
4. Ameliorated to maintain pH 5.2 in the 0–10 cm	4.7	Surface applied, 1 application (trigger for re-application @ 5.0 pH in 0–10 cm layer)
5. Ameliorated to maintain pH 5.2 in the 0–10 cm	4.7	Surface applied and incorporated, 1 application (trigger for reliming @ 5.0 pH in 0–10 cm layer)
6. Ameliorated to maintain pH 5.8 in the 0–5 cm	2.9	Surface applied, 1 application (trigger for reliming @ 5.5 pH in 0–5 cm layer)
7. The 'once-in-a–generation' treatment. Ameliorated to maintain pH 5.8 in the 0–20 cm	7.0	Surface applied and incorporated: like treatment 3 with higher lime rate (incorporated) to ameliorate acidity to 20 cm and prevent acidification in the long-term with a single incorporation

Lime was applied with a direct-drop spreader on 5 February 2020 and the incorporated treatment plots were cultivated with single pass of a Horsch Tiger 3 MT combination cultivator. Pasture was sown on 5 April 2021 by the farmer, in common with the larger paddock, to a mixture that included phalaris (*Phalaris aquatica*), arrowleaf clover (*Trifolium vesiculosum*) and subterranean clover (*Trifolium subterraneum*) at a total sowing rate of 12 kg/ha, with MAP fertiliser at 100 kg/ha. The trial was grazed in conjunction with the surrounding pasture with a commercial sized cattle herd as convened by the farmer.

The trigger for re-liming was reached in treatment six (low initial rate of lime with more frequent applications, pH target 5.8 at 0–5cm). Following grazing to reduced herbage cover, lime was broadcast at 1.3 t/ha on the 16 March 2025 via a direct drop spreader.

Soil sampling

Soil sampling occurred in autumn each year. Twenty cores (24 mm diameter) were placed randomly across a transect of each plot and inserted to a depth of approximately 40 cm using a 4-stroke driver with a jack-hammer mechanism. Soil cores were sectioned into 10 depth increments; at 2.5 cm intervals to 20 cm, then at 5.0 cm intervals to 30 cm, then bulked for each depth. Soil below 30 cm was discarded. Samples were dried in a fan-forced dehydrating oven at 40°C for 72 h and later homogenised through a 2 mm sieve. Samples were dispatched to the NSW DPI laboratories at Wollongbar to quantify pH (using a $CaCl_2$ extract), available phosphorus (Colwell), total carbon (LECO), and exchangeable cations including aluminium.

Pasture sampling

Plots were assessed in autumn (17 May 2022) and late winter (24 August 2022) for pasture botanical composition, and dry matter production of the control, lime incorporated to pH 5.2 (0–10 cm) and pH 5.8 (0–10 cm) treatments.

Pasture botanical composition was assessed by using the dry-weight-rank method (Mannetje and Haydock 1963), a non-destructive method that has been shown to provide an accurate estimate of the botanical composition of pastures. Briefly, the percentage of each species within the sward was ranked in a quadrat (0.1 m^2) at twenty positions along a transect line in each plot. Pasture composition was grouped for sown species (phalaris and clovers), annual grass weeds (AGW) and broadleaf weeds (BLW) with the average yield for each sward component calculated for each treatment.

At the time of botanical composition assessment, herbage dry matter production was also visually assessed in the same transect of 20 quadrates. Visual scores were calibrated by cutting 10 representative quadrats to 1 cm, encompassing the full range of scores given at each sampling time. Each sample was dried at 60°C for 48 h and weighed. Visual scores were converted to standard units (kg DM/ha) using a regression function between visual scores and the calibrated dry matter sample for each plot ($r^2 = 0.93$).

Phalaris basal frequency was assessed in November 2024 at four random positions per plot using a 100 cm × 100 cm quadrate divided into 10 cm × 10 cm cells and counting the number of cells containing one or more phalaris tillers emerging from the soil. The basal frequency of subterranean clover and arrowleaf clover were also assessed at the same time.

Results and Discussion

The Lyndhurst site has extreme acidity to 30 cm (Fig. 1a) resulting in concentrations of exchangeable aluminium of greater than 50% in the 10–20 cm layer of the profile (Fig. 1b). Two years after application, there were no significant differences in the soil pH profiles created from surface application of lime (without incorporation) at rates to achieve pH 5.2 or pH 5.8 in the soil. Surface applications of lime significantly increased pH to a depth of 7.5 cm within 2 years. These treatments also decreased exchangeable aluminium concentration relative to the control to a depth of 15 cm.

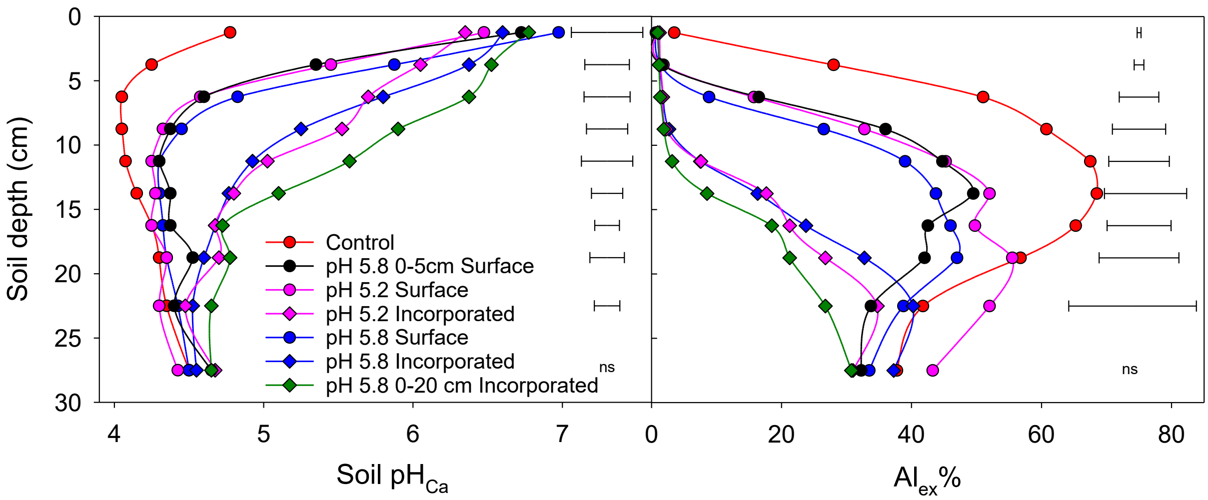

Figure 1 Soil pH ($CaCl_2$) (a) and exchangeable aluminium (Al_{ex} %) (b) in 2022 at Lyndhurst. Horizontal bars indicate LSD (*P* = 0.05). ns= no significant difference.

Deep incorporation of lime increased pH relative to the untreated soil to 17.5 cm, although the surface 0–2.5 cm were similar for all lime rates and methods of application. Deep incorporation of lime significantly decreased exchangeable aluminium to a depth of 20 cm relative to the control and effectively removed exchangeable aluminium to 12.5 cm.

Four years after lime application, the pH 5.8 (0–20 cm) treatment had a significantly greater soil pH in the 0–2.5, 7.5–10, and 10–12.5 cm layers than the pH 5.8 (0–10 cm) treatment and all layers of the pH 5.2 incorporated treatment to a depth of 17.5 cm (Fig. 2a). The pH 5.8 (0–5 cm) treatment increased pH relative to the control to a depth of 7.5 cm but had acidified relative to previous years, approaching the trigger to re-lime. Therefore, this treatment was re-limed in 2025 with 1.3 t/ha of lime applied to the soil surface.

The surface application of pH 5.2 and pH 5.8 treatments resulted in the greatest soil pH in the 0–2.5 cm layer. The pH of the surface pH 5.2 and pH 5.8 (0–10 cm) treatments decreased with depth and were no different to the control at a depth of 17.5 cm and 22.5 cm, respectively.

The lime application treatments clearly decreased exchangeable aluminium concentration relative to the control (Fig. 2b). Deep incorporated lime significantly decreased exchangeable aluminium concentration to between 0 and 15% to a depth of 30 cm, with no significant difference observed between incorporated treatments. Incorporated lime treatments were significantly more effective at removing exchangeable aluminium compared to the same rates when only surface applied, which still had approximately 20–30% aluminium in layers below 10 cm. However, these concentrations still represented a significant decrease compared to the control to a depth of 20 cm (Fig. 2b).

Comparison of the 2022 (Fig. 1) and 2024 (Fig. 2) data indicates movement of alkali downwards from surface applied lime with pH increasing to 12.5 cm and exchangeable aluminium decreasing to 20 cm. In the incorporated treatments, the decrease in exchangeable aluminium concentration has continued to move down the profile relative to 2022 data.

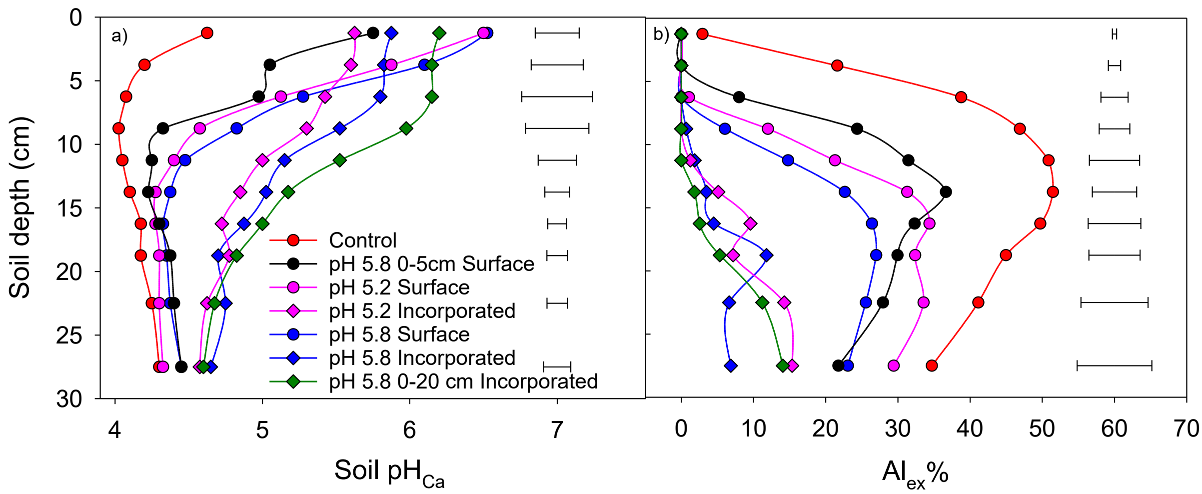

Figure 2. Soil pH (CaCl$_2$) (a) and exchangeable aluminium (Al$_{ex}$ %) (b) in 2024 at Lyndhurst. Horizontal bars indicate LSD (*P* = 0.05). ns= no significant difference.

Pasture production

Lime significantly increased pasture production in May 2022 (Fig. 3). The unlimed control produced a total dry matter of only 366 kg, approximately half the pasture dry matter of the lime treatments (721 kg/ha). There were no differences in total dry matter between treatments of incorporation with pH targets of 5.2 or 5.8 in either May or August.

Significant pasture botanical composition differences were evident across the treatments in May (Fig. 3). Annual grass weeds were greater in the control compared to the lime treatments, averaging 61.5% (214 kg/ha) and 11.6% (82 kg/ha), respectively. Phalaris dominated the pasture sward across both lime treatments, averaging 82.4% (598 kg/ha) compared to 21.5% (95 kg/ha) in the control. The composition of BLW and clover did not differ between treatments, averaging 7.2% (32.9 kg/ha) and 2.5% (14.3 kg/ha), respectively. It was observed that the cattle were selecting palatable pasture species such as phalaris in preference to AGWs. However, pasture production increases were evident across all treatments in August (Fig. 3). The lime treatments averaged greater total pasture dry matter compared to the control; 1833 kg DM/ha and 1422 kg DM/ha, respectively. The lime incorporated to pH 5.2 or pH 5.8 treatments did not differ in average pasture dry matter. At the August sampling, AGW in the control recorded the same dry matter as phalaris in the lime treatments (Fig. 3). The proportion of clover in the control was greater than that in the incorporated lime to pH 5.8 treatment, 9.9% (142 kg/ha) and 2.8% (49 kg/ha), respectively. The increased density of phalaris, in response to lime, negatively affected clover production in August 2022.

The basal frequency of phalaris in 2024 was greater with the addition of lime (*P* = 0.001) compared to the nil treatment (Fig. 4). The basal frequency of arrowleaf clover was low (<20%) but tended to be higher where higher rates of lime were previously incorporated. There was no statistically significant relationship between subterranean clover frequency and soil treatment.

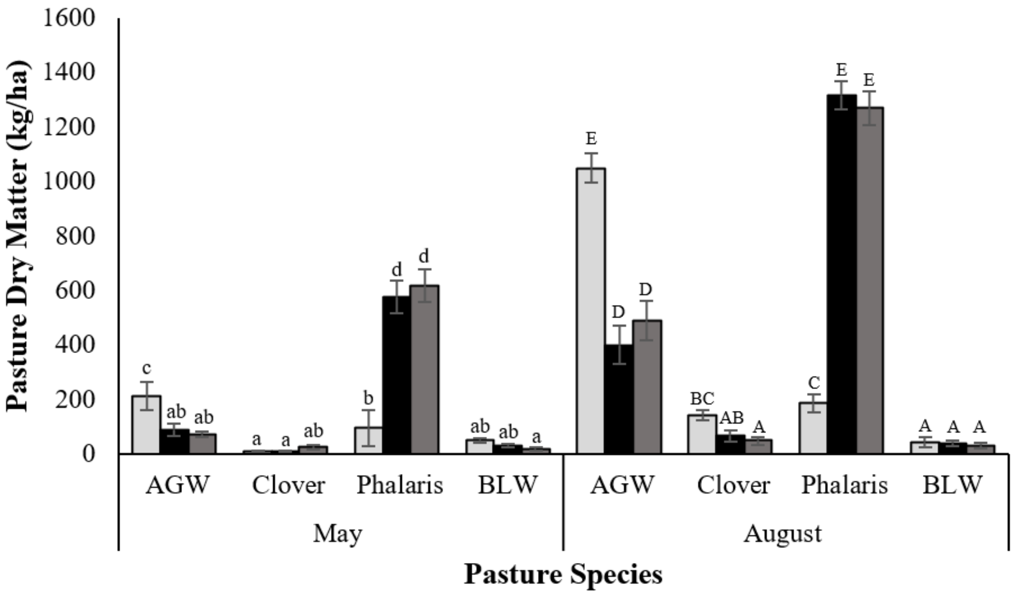

Figure 3. The average pasture botanical composition for the control (light grey), incorporated lime to pH 5.2 (0–10 cm) (black) and pH 5.8 (0–10cm) (dark grey) treatments in May and August 2022 for the Lyndhurst field site. Vertical bars represent the standard error of the mean. Letters represent significant difference (LSD = *P* < 0.05). *Note:* May and August were not statistically compared to each other. AGW= annual grass weeds, BLW= broadleaf weeds.

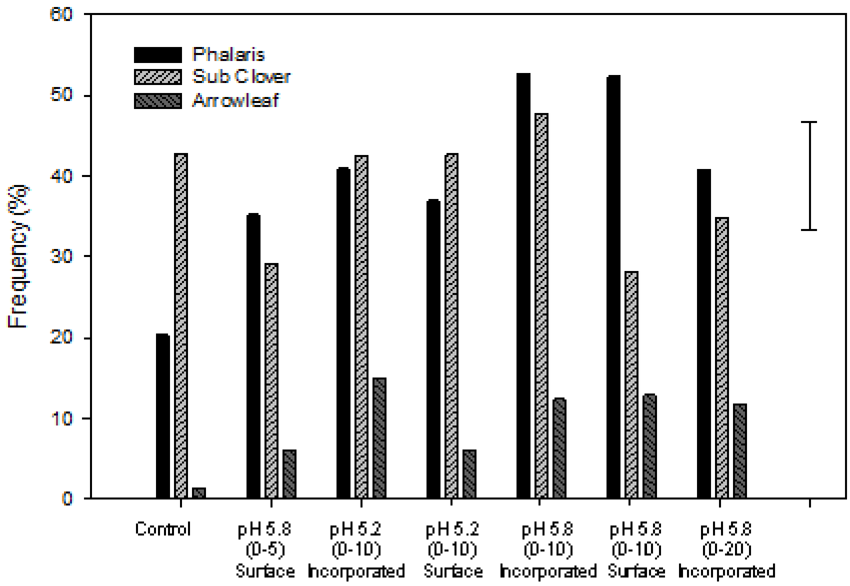

Figure 4. Basal frequency for phalaris, subterranean clover and arrowleaf clover measured across seven rates of lime application at Lyndhurst in 2024. Significant difference (LSD = *P* < 0.05) is shown for phalaris, no significant differences existed for other species.

Conclusions

The Lyndhurst site has demonstrated that incorporation of lime provides rapid (2 years) amelioration of acidity which will improve pasture production. This was driven by a growth response in phalaris once acidity was removed. This phalaris response also improved pasture composition by outcompeting AGW. This was an enduring response and was measured as an increase in basal frequency of phalaris in 2024, four years after lime application. The plant production data presented does not show a benefit in the marginal difference in liming to go from the pH 5.2 to pH 5.8 target when incorporated. The soil data show that both these treatments have ameliorated acidity to at least 15 cm when incorporated and to 7.5 cm from surface application. Though the long-term benefit of these approaches remains to be seen, the change from 2022 to 2024 data indicates that the higher pH target is increasing soil pH and decreasing toxic aluminium with depth compared to the traditional pH target.

Acknowledgements

This research was supported by Grassland Society of NSW Inc., DAFF, Charles Sturt University, MLA and NSW DPIRD.

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