

Medium-term soil pH and exchangeable aluminium response to liming at three high country locations

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Abstract

Acid soil conditions and associated aluminium (Al) toxicity pose a serious impediment to legume establishment, persistence and productivity in high country. However, data that report soil exchangeable Al concentrations in response to lime applications are scarce. Three historical (3–8-year-old) lime trial soils were sampled for soil pH and exchangeable aluminium (Al). Soil pH ranged from 4.8 to 7.5, with exchangeable Al concentrations (CaCl₂ extraction) of 0.2 to 24 mg Al/kg. Soil pH and exchangeable Al changed significantly when lime was applied, but the shape of the response differed between the three site locations. The soil pH changes (0–7.5 cm horizon) were 0.16, 0.10 and 0.20 pH units/t lime applied. Critical research needs to be conducted to investigate the key soil factors and mechanisms that result in Al toxicity in high country soils to enable development of mitigation strategies. On-farm decisions on lime rates and legume species suitability need to be based on soil pH and Al testing from individual farm blocks rather than using “rule of thumb” approaches.

Keywords: soil pH, soil exchangeable aluminium, lime, pasture legumes

Introduction

Many South Island high country soils have low soil pH and possibly high exchangeable Al concentrations. Soil acidity (low soil pH coupled with toxic concentrations of exchangeable aluminium) and low available phosphorus (P) and sulphur (S) may also limit establishment and maintenance of legumes (Moir *et al.* 2000; Haynes & Williams 1993). To neutralise increased soil acidity, lime must be applied, and where this cannot be done economically, soils may be too acidic for legumes and productivity declines sharply (Edmeades *et al.* 1983; Lanyon & Griffith 1988). Valuable dryland forages, such as lucerne (*Medicago sativa* L.), are intolerant of acid soil conditions and related aluminium (Al) toxicity (Rechcigl *et al.* 1988; Su & Evans 1996). Often the cost of lime or its application is uneconomic in extensive high country regions. In many cases the rate of penetration of the effects of

surface applied lime, and subsequent pasture response, are unknown. Incorporation of lime may be possible on flatter land but the risk of wind erosion means direct drilling is the preferred establishment technique. The relationship between pasture production and soil pH is well established on some high country soils and the critical concentrations of exchangeable Al (Haynes & Williams 1993) and the relative Al tolerance of some forage legumes have also been examined (Edmeades *et al.* 1991; Wheeler *et al.* 1992). However, studies of soil pH changes with surface applied lime, and associated changes in soil exchangeable Al at the surface and at depth over time, in South Island high country soils are scarce.

Previously, Moir & Moot (2010) reported on the effects of surface applied lime on lucerne in an acid high country soil. Horizontal, restricted, root growth related to Al toxicity issues were reported, along with soil pH and exchangeable Al changes resulting from lime applications. This paper updates results from a from this field experiment and also reports results from two additional established lime trials in the South Island high country. The aim of this study was to examine the effects of lime rate on pH and soil exchangeable aluminium concentrations of three acid high country soils at different locations.

Methods

Site description and trial design

Three historical lime field trials were examined. Site 1 was located at Mt Pember station, North Canterbury (Moir & Moot 2010); Site 2 was Glenmore station, located on the southern banks of Lake Tekapo, central Canterbury; and Site 3 was Glenfoyle station, near Lake Hawea, Central Otago. Site specific information and treatment lime rates are presented in Table 1.

AgLime was surface applied at Site 1 in March 2008, followed by sowing of ‘Grasslands Kaituna’ lucerne. Further details of the Mt Pember Station experimental area are given by Moir & Moot (2010) and Fasi *et al.* (2008). All plots were soil sampled to 15 cm depth in September 2013. Glenmore Station (Site 2) is a pasture experimental site (Moot & Pollock 2014). AgLime was surface applied in replicate blocks (20×10 m plots; 2

replicates) in October 2010 and soil samples (30×2.5 cm cores; 0–15 cm deep) were taken in March 2013. Glenfoyle Station (Site 3) consists of 5×10 m pasture plots on hill slopes with treatments replicated four times (Espie 2008). AgLime was surface applied in April 2005 and soil samples (15×2.5 cm cores; 0–15 cm or 0–7.5 cm deep in stony ground) taken in December 2012. All soil samples were analysed for pH (1:2.5 soil: water ratio) and exchangeable aluminium (0.02 M CaCl₂ extraction followed by inductively coupled plasma atomic emission spectroscopy (ICP-OES) analysis.

Results

Lime effects on soil pH

Soil pH differed with horizon depth and lime rate at all three sites. Five years after the initial lime application at Site 1 (Mt Pember Station), soil pH was higher at

0–7.5 cm than the 7.5 to 15 cm, soil depths. The pH in the 0–7.5 cm horizon increased in a linear fashion with lime, to a maximum of 6.7 at 8 t lime/ha (Table 2). In the 7.5–15 cm horizon, pH was unaffected by lime rate, except at 8 t/ha, where it increased to 6.1. At Site 2 (Glenmore station), moderate increases in soil pH were observed in the 0–7.5 cm horizon three years after lime was applied, but not in the 7.5–15 cm horizon. At Site 3 (Glenfoyle Station), large increases in soil pH occurred in the 0–7.5 cm horizon in response to lime applications eight years after application. The maximum increase was 0.8 pH units at 4 t lime/ha. Only minimal increases in pH were observed with increasing lime rate for the 7.5–15 cm horizon at this site. In terms of soil pH change per unit of lime applied, changes for the 0–7.5 cm horizon were 0.16, 0.10 and 0.20 pH units/t lime applied at Sites 1, 2 and 3 respectively.

Table 1 Site physical information and treatment lime rates for three historical high country field trials.

Site	Location	Annual Rainfall (mm)	Altitude (m a.s.l.)	Topography	Soil Group	Lime Rates (t/ha)
1: Mt Pember Station	North Canterbury	600	430	Flat	Stony Brown Soil	0, 2, 4, 8
2: Glenmore Station	Central Canterbury	600	700	Flat - rolling	Brown soil	0, 3, 5
3: Glenfoyle Station	Central Otago	600	750	Hill (15–20°)	Dense brown hill soil	0, 0.13, 0.25, 0.5, 2, 4

Table 2 Soil pH and exchangeable Al values for three high country field trial sites at two soil horizon sampling depths (0–7.5 and 7.5–15 cm).

Site	Lime Rate (t/ha)	pH		Exchangeable Al (mg/kg)	
		0–7.5 cm	7.5–15 cm	0–7.5 cm	7.5–15 cm
1: Mt Pember Station	0	5.4	5.6	3.0	5.6
	2	5.7	5.7	2.2	4.4
	4	6.1	5.6	1.2	5.5
	8	6.7	6.1	0.5	1.9
	<i>sem</i>	0.09	0.12	0.20	1.40
2: Glenmore Station	0	4.9	5.3	5.0	5.1
	3	5.5	5.2	2.2	5.9
	5	5.4	5.2	2.6	4.9
	<i>sem</i>	0.05	0.04	0.82	0.80
3: Glenfoyle Station	0	5.5	5.2	3.1	17.3
	0.13	5.6	5.1	3.5	17.4
	0.25	5.6	5.3	3.0	13.0
	0.5	5.6	5.3	3.9	13.5
	1.0	5.8	5.3	1.5	9.8
	2.0	6.0	5.3	1.4	11.8
	4.0	6.3	5.3	1.1	9.2
	<i>sem</i>	0.11	0.03	0.90	0.91

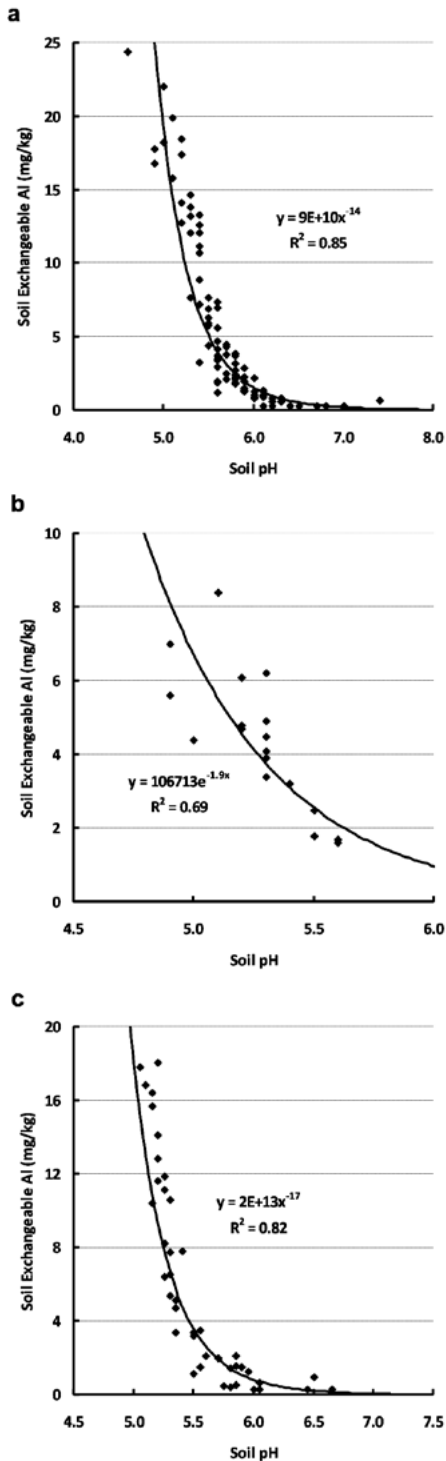


Figure 1 The relationships between soil pH and soil exchangeable Al at **a**, Site 1 (Mt Pember station); **b**, Site 2 (Glenmore Station); and **c**, Site 3 (Glenfoyle Station).

Lime effects on exchangeable aluminium concentrations

Soil exchangeable Al concentrations were strongly affected by lime rate. Comparing the highest lime rate at each site, soil exchangeable Al dropped by 2.5, 2.4 and 2.0 mg Al/kg at Sites 1, 2 and 3, respectively for the 0–7.5 cm horizon. In the 7.5–15 cm horizon, changes in exchangeable Al concentrations were minimal, except at the oldest Site 3, where 4 t lime/ha caused a reduction of 8.1 mg Al/kg.

Relationships between soil pH and exchangeable aluminium

Over all soil sampling depths and liming rates, soil pH was strongly associated with soil exchangeable Al concentrations at all sites (Figure 1). Exponential curves were appropriate to describe the relationships at sites 1 ($R^2=0.85$) and 3 ($R^2=0.83$), but a polynomial curve was required at site 2 ($R^2=0.69$). Soil exchangeable Al was low (1–2 mg/kg) within the soil pH range of 6.0–7.0. However, exchangeable Al concentrations rose sharply to 2–3 mg/kg when pH fell below 5.7. At a pH of 5.5, exchangeable Al increased to 5.0, 2.5 and 4.0 mg/kg at sites 1, 2 and 3 respectively. Increases in exchangeable Al below pH 5.5 were near linear at sites 1 and 3, increasing at 3–4 mg Al/kg per 0.1 pH unit decrease in pH. At site 2, increases in exchangeable Al below pH 5.5 were 1 mg Al/kg per 0.1 pH unit decrease in pH.

Discussion

This study has determined the effects of historic liming on soil pH at three high country locations, and in turn, on exchangeable Al, in two surface soil horizons. Strong relationships between soil pH and exchangeable plant-available Al were established for these soils, whereby soil exchangeable Al increased exponentially below a soil pH of 5.7. The “change points” on the curves for Sites 1 and 3 are strong evidence that these soils are very sensitive to pH change. Importantly, below pH 5.7, Al concentrations increase rapidly to values that are toxic to many legumes. This result generally agrees with that reported by Hochman *et al.* (1992) for three New Zealand Brown soils, but does not follow in soils of different age and mineralogy. For example, Mullen *et al.* (2006) reported low exchangeable Al of 1.3 mg/kg at pH 4.4 (CaCl_2) in a soil (Red Chromosol, granitic parent material) in New South Wales. Our results also highlight the problem of higher soil-exchangeable aluminium concentrations (at “typical” field soil pHs) in Brown soils, which are common to South Island high country. Also noteworthy, is the variable relationship between soil exchangeable Al and soil pH, and that relationships between these indices appear to be soil or site specific. Further detailed research is required to determine the key mechanisms driving the site-to-site variations in these relationships.

Liming had a strong medium-term effect on soil pH at all three sites, especially in the 0–7.5 cm soil horizon. Soil pH increased an average of 0.16 units/t lime applied. This result agrees with Wheeler & Edmeades (1995) and Black & Cameron (1984). Liming reduced soil exchangeable Al concentrations in the surface soil horizon by 2.0–2.5 mg/kg, even 3–7 years after application. This result demonstrates that exchangeable

Al at the soil surface can be reduced to safe values, even several years after lime application. At a soil pH of 5.5, exchangeable Al increased to 3.0 mg/kg or above. At this level, exchangeable Al is likely to reduce DM yield (Wheeler *et al.* 1992; Moir & Moot 2010). Consequently, on-farm decisions on lime rates and legume species suitability need to be based on soil pH and Al testing from individual farm blocks rather than using “rule of thumb” approaches across farms.

The measurable effects of lime were less obvious in the deeper soil horizon, with only modest changes in soil pH and exchangeable Al. At site 1, lime at 8 t/ha increased soil pH by about 0.5 pH units in the 7.5–15 soil horizon, but lower lime rates had little effect. This increase in soil pH resulted in a corresponding drop in exchangeable soil Al from 5.6 to 1.9 mg/kg. Importantly, this reduction in Al represents a change to non-toxic concentrations in the 7.5–15 cm horizon at Site 1, 5 years after the initial application. This contrasts with no reduction in exchangeable Al being observed in earlier measurements at this site (Moir & Moot 2010), and reinforces the importance of running trials for longer time spans to determine the longer-term effects of climate and its variability on the response to lime in these high country environments. Interestingly, no soil pH or Al changes occurred in the 7.5–15 cm horizon at Site 2 as a result of liming. This is the youngest site and mirrors the lack of response in this horizon previously seen at Site 1. Further monitoring will continue at this site. The implication is that even at a rate of 5 t/ha, surface-applied lime is unlikely to reduce plant-available soil aluminium to safe concentrations for legume growth in the 7.5–15 cm horizon at Site 2 within 3 years. Thus, the application of lime should occur prior to 3 years of winter forage, crops such as ryecorn, to break down the resident vegetation. However, even this may be insufficient to allow the successful establishment of aluminium sensitive legumes, and alternatives such as *Lupinus polyphyllus* may be required (Moot & Pollock 2014). As it stands, plant root depth and therefore available water content of the soil are likely be compromised at Site 2, which may impact on yield and persistence (Mullen *et al.* 2006; McGowan *et al.* 2003; Teixeira *et al.* 2006; Grewal & Williams 2003). At Site 3, Al concentrations were reduced to “safe” values (< 3 mg Al/kg; Moir & Moot 2010) in the 0–7.5 cm horizon at lime rates of 1t/ha and above. However, background Al were much higher in the 7.5–15 cm horizon at this site. Consequently, although Al was substantially reduced in the deeper horizon (again, by lime rates of 1 t/ha and above), Al concentrations were still around 10 mg/kg, and so remained toxic to most pasture legumes. Ongoing research at Lincoln University is looking at the effect of incorporation of lime in cultivation or subsoil lime application so that soil pH

is increased at depth. These very high Al concentrations in the 7.5–15 cm horizon at Site 3 contrast with those of the other two sites in this study, and highlight the variability of soil exchangeable Al due to site specific factors, which are currently poorly understood. This study has highlighted the importance of conducting longer-term soil measurements in order to develop a fuller understanding of the effects of lime. Repeated measurements in a time sequence are therefore required to improve our understanding. Ideally, further research is required to explain the key factors driving variability in soil exchangeable Al concentrations.

Conclusions

- Soil pH was strongly related to concentrations of soil exchangeable Al.
- Surface applied lime increased soil pH and reduced soil exchangeable aluminium, especially at higher lime rates.
- Surface applied lime took 5–8 years to produce observable changes in the 7.5–15 cm zone.
- The effect of lime on soil pH and exchangeable Al varied between sites, which highlights the lack of current understanding of mechanisms driving exchangeable Al concentrations.
- On-farm decisions on lime rates and legume species suitability need to be based on soil pH and Al testing from individual farm blocks rather than using “rule of thumb” approaches.

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