Soil pH, exchangeable aluminium and lucerne yield responses to lime in a South Island high country soil

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Abstract
A 2-year field experiment was conducted on a high country brown stony soil in the Lees Valley, North Canterbury. Two forms of lime ('AgLime' and 'Quicklime') were applied at 4 rates (0, 2, 4 and 8 t/ha) and plots sown with 'Grasslands Kaituna' lucerne. Soil pH was strongly (R^2=0.73) related to exchangeable aluminium (Al), with a sharp rise in plant-available Al levels below a pH of 5.8. Soil pH changes of 0.15 units/t lime applied in the 0-7.5 cm horizon, and lower, variable, pH changes in the 7.5-15 and 15-30 cm horizons were achieved. Soil exchangeable Al dropped to low levels (< 0.3 me/100g) at all liming rates in the 0-7.5 cm soil horizon, and had a moderate to low effect in deeper soil horizons. Increases in soil exchangeable Al below soil pH 5.8 were linear, increasing at 0.2 me Al/100g per 0.1 pH unit decrease in soil pH. Effects of lime form were unclear. Lucerne yields were often low, in the order of 700-1 200 kg DM/ha, and were not influenced by lime rates or soil exchangeable Al. Other, soil and climate variables are discussed in relation to current DM yields. Measurements at this site are on-going.
Keywords: alfalfa, lucerne, lime, soil pH, dry matter yield, climate

Introduction
The productivity of South Island hill country is typified by a short, often soil moisture limited growing season. Alternative pasture species have been suggested to improve dryland pasture production (Brown *et al.* 2003; McGowan *et al.* 2003), and moreover, the deep-rooting nature of lucerne (*Medicago sativa*) has highlighted this species for dryland environments (Brown *et al.* 2009; Thomas 2003). However, lucerne is intolerant of acid soil conditions, and related aluminium (Al) toxicity (Rechcigl *et al.* 1988; Su & Evans 1996).

On about 500 000 ha of farmed high country, soils have low soil pH and possibly high soil Al. Soil acidity (low soil pH coupled with toxic levels of soil 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 offset increased soil acidity, lime must be applied, and where this cannot be done, soils may be too acidic for legumes and productivity declines sharply (Edmeades *et al.* 1983; Lanyon & Griffith 1988). Often the cost of lime is uneconomic in extensive high country, and the response to liming unknown. The relationship between pasture production and soil pH is well established on some soils and the critical level of soil 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 liming, and associated changes in soil exchangeable Al, in South Island high country soils are scarce.

A previous experiment on this site showed poor lucerne yields, and problems with seedling establishment (Lewis 2007). Evidence of horizontal, restricted, root growth suggests soil acidity, and related toxicity issues. This paper summarises results from a field experiment, that examined the effects of lime rate and type on soil exchangeable aluminium levels down the profile of an acid high country soil.

Methods
Site description and trial design
The field study at Mt Pember Station in the Lees Valley, North Canterbury, is on a high country brown stony soil (New Zealand classification: High Country Brown shallow stony soil; USDA classification: Inceptisol). The altitude is 430 m.a.s.l. with annual rainfall of 600 mm. Further details of the trial site were given by Fasi *et al.* (2008) where forage crops had been grown, and where soil fertility was pH 5.3, Olsen P 12 µgP/mL and sulphate S 8 µgS/g. The site was sprayed with glyphosate (3 L/ha; 540 g a.i./L) in February 2008 and plots marked out a month later. The trial consisted of 16, 10 x 20 m plots in a randomised design. Treatments were standard 'AgLime' ($CaCO_3$) or 'Quicklime' (CaO), at 4 rates (0, 2, 4 and 8 t/ha), in 2 replicates. Lime was surface applied in March 2008. Basal maintenance superphosphate (300 kg/ha; 24 kg P and 62 kg S/ha) was applied in September 2008. In October 2008 plots were soil sampled at 0-7.5, 7.5-15 and 15-30 cm depths (25 mm diameter x 300 mm deep cores; 20 cores per plot, bulked). Where stones prevented

coring, a trowel was used to obtain the deeper samples. Soil samples were analysed for pH (1:2.5 soil: water ratio) and exchangeable aluminium (1M KCl extraction followed by ICP-OES analysis). The variability of soil pH, soil Al and lucerne yield was analysed by analysis of variance (ANOVA) using GenStat 11.0 (Lawes Agricultural Trust, Rothamsted, UK). The model included lime type, lime rate, soil horizon depth and interactions as fixed effects.

Crop sowing and trial management

The site was re-sprayed with glyphosate (4 L/ha; 540 g a.i./L) in November 2008. 'Grasslands Kaituna' lucerne was direct-drilled at 14 kg/ha of coated seed on 4th December 2008. Emergence was measured on December 22nd (cotyledon stage; 37 plants m^2) from 2 x 1 m lengths of drill row per plot multiplied by the 15 cm row spacing. Lucerne dry matter (DM) yield was measured at regular intervals over 2 years on all plots using a 'pasture capacitance probe' (JenQuip, Fielding), calibrated to DM cuts at each measurement. Calibration cuts involved 20 probe readings across a range of stand heights of 0.2 m^2 quadrats before cutting at 1-2 cm above the ground, drying and weighing. In March 2009 the trial site was 'grid sample' surveyed (20 points per plot) for topsoil depth (depth to gravel) using a metal spike with depth graduation. Climate (rainfall, air and soil temperature, topsoil moisture) was measured on-site using an automated weather station.

Results

Soil pH and aluminium levels

Over all soil sampling depths and liming rates, soil pH was strongly (R^2 = 0.73) associated with soil exchangeable Al levels (Fig. 1). A sigmoidal curve described the relationship. Soil exchangeable Al was low (0.1-0.2 me/100g) within the soil pH range of 5.8-7.0. However, exchangeable Al levels rose sharply to 0.4 me/100g when pH fell below 5.8. At a pH of 5.5, exchangeable Al increased to 1.0 me/100g, and values

Figure 1 The relationship between exchangeable soil aluminium and soil pH at Lees Valley, North Canterbury.

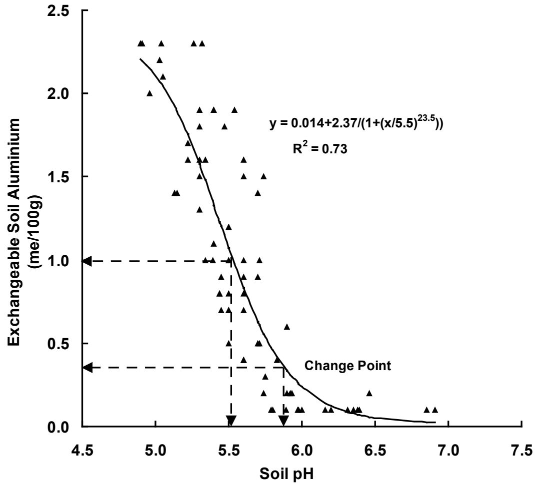


Table 1 Soil pH values for three soil horizons for 'AgLime' and 'Quicklime' treatments applied to soils at a trial site at Lees Valley, North Canterbury.

Soil depth (cm)	Lime rate (t/ha)	'AgLime'		'Quicklime'	
		Soil pH	Soil Al	Soil pH	Soil Al
0 – 7.5	0	5.4	0.9	5.5	0.9
	2	6.0	0.1	5.7	0.2
	4	5.9	0.2	6.1	0.1
	8	6.3	0.1	6.9	0.1
7.5 – 15	0	5.3	1.3	5.2	1.4
	2	5.9	1.0	5.2	2.1
	4	5.6	0.6	5.7	1.7
	8	5.9	0.3	6.0	0.6
15 – 30	0	5.3	2.0	5.2	1.7
	2	5.5	1.2	5.0	2.1
	4	5.4	1.4	5.7	1.2
	8	5.6	1.3	5.9	0.9
$LSD_{5\%}$	Lime Rate	0.4	0.7	0.6	0.8
	Soil Depth	0.3	0.6	0.5	0.8

Figure 2 Mean dry matter (DM) yields of lucerne crops on 19 March 2009, grown with different lime forms and rates in the Lees Valley, North Canterbury. Error bars represent 1 SEM.

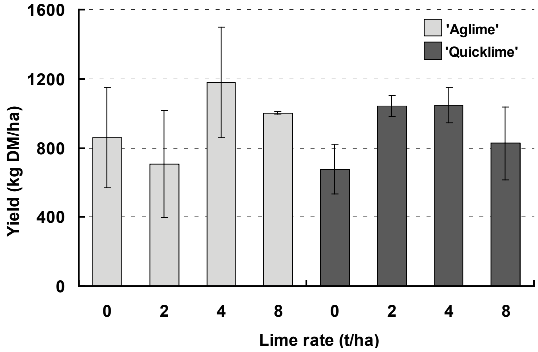
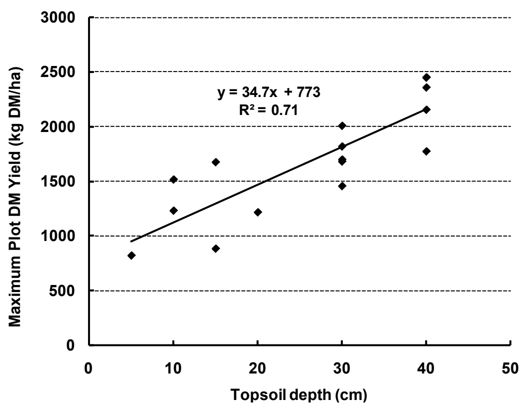


Figure 3 Relationship between maximum 'sub-plot' dry matter (DM) yield and topsoil depth (depth to gravel), of lucerne crops grown in the Lees Valley, North Canterbury.



above 2.0 me/100g were measured at a pH of 5.0. Increases in exchangeable Al below pH 5.8 were linear, increasing at 0.2 me Al/100g per 0.1 pH unit decrease in pH.

Lime effects on soil pH and aluminium levels

Soil pH differed with horizon depth ($P<0.01$) and lime rate ($P<0.001$), though lime type had no significant effect. Likewise, soil Al differed with horizon depth ($P<0.01$) and lime rate ($P<0.05$), with no difference between lime types. The unlimed pH (0-7.5 cm horizon) was slightly lower and plant-available Al higher than in the subsoil horizons (Table 1). At the 'baseline' (unlimed) pH of 5.3-5.4, soil exchangeable Al levels were 0.9-2.0 me/100g. Liming increased pH and lowered plant-available Al at the surface (0-7.5 cm) soil horizon. Soil pH generally increased in a linear fashion in this horizon with increasing lime rate, to a maximum pH of 6.3 for 'AgLime' and 6.9 for 'Quicklime' (Table 1). Correspondingly, exchangeable Al levels were low (0.1-0.2 me/100g) for all lime treatments in this horizon. Increases in pH resulting from liming were also linear in deeper horizons, though the pH shift was lower, and more variable. Exchangeable Al was in the medium to high range (0.6-2.1 me/100g) in this horizon even after lime was applied at 2-4 t/ha.

Comparable but inconsistent pH changes occurred at the 15-30 cm depth, with soil Al remaining at moderately high levels in this horizon. 'Quicklime' appeared to have a greater effect on pH and exchangeable Al levels than 'AgLime' in this deeper horizon, but the data were variable. 'AgLime', at 8 t/ha, increased pH from 5.3 to 5.6 in this horizon, and reduced exchangeable Al from 2.0 to 1.3 me/100g (Table 1) compared with a pH increase from 5.2 to 5.9 and an Al reduction from 1.7 to 0.9 me/100g for the 'Quicklime'.

Lucerne yield

Lucerne DM yield was low at this trial site, and not related to lime rate or product. Results from a 'typical' DM measurement are presented in Fig. 2. Yields ranged from 700-1 200 kg DM/ha and were not affected by lime rate, pH or exchangeable Al. This suggests that factors other than lime were controlling plant yields. Lucerne yields did show some response at medium liming rates at some measurement times, though data were variable and require confirmation.

A preliminary survey of topsoil depth (depth to gravel) at the trial site indicated it is extremely variable, even over 1-2 m distances. Of all variables measured, lucerne yields were best explained ($R^2 = 0.71$; Fig. 3) by topsoil depth when individual plots were split into four 'sub-plots'.

Discussion

The objective of this study was to determine the effects of liming on soil pH, and in turn, on exchangeable Al and lucerne yield in South Island high country. A strong relationship between soil pH and exchangeable plant-available Al was established for this soil, whereby soil exchangeable Al increased sharply below a soil pH of 5.8. 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 0.4 me/100g at pH 4.4 ($CaCl_2$) in a soil (Red Chromosol, granitic parent material) in NSW. Our results highlight the problem of higher soil-exchangeable plant-available aluminium levels (at 'common' 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 plant Al uptake, and that relationships between these indices are soil or site specific (Rechcigal *et al.*

1988). Further studies are required to establish such relationships at this site.

Liming had a strong effect on soil pH, especially in the 0-7.5 cm soil horizon, where pH increased an average of 0.15 units/t lime applied. This result agrees with Wheeler & Edmeades (1995) and Black & Cameron (1984). Differences in the effect of lime product were not significant due to the variability of soil pH data. Liming reduced soil exchangeable Al levels in the surface soil horizon from 0.9 to 0.1-0.2 me/100 g. This is an important result, and demonstrates that exchangeable Al at the soil surface can be reduced to safe levels, even at low liming rates. At a soil pH of 5.5, exchangeable Al increased to 1.0 me/100g or above. At this level, exchangeable Al is likely to reduce DM yield (Wheeler *et al.* 1992).

The measurable effects of lime were less obvious in deeper soil horizons, with only modest changes in soil pH and exchangeable Al. Lime at 8 t/ha increased soil pH by about 0.5 pH units in the 7.5-15 and 15-30 cm soil horizons. This increase in soil pH resulted in a corrresponding drop in exchangeable soil Al of around 1.0 me/100g at the 8 t/ha lime rate to around 0.45 and 1.1 meAl/100g for the 7.5-15 and 15-30 cm soil horizons, respectively. The implication is that even at a rate of 8 t/ha, surface-applied lime is unlikely to reduce plant-available soil aluminum to levels safe for lucerne growth in the short-term in this environment.

Lucerne growth, and therefore yield, has been restricted at this site. Yields were comparable to those of Mullen *et al.* (2006) and lower than those reported by McGowan *et al.* (2003), Teixeira *et al.* (2006) and Grewal & Williams (2003). Any effects of liming, and associated soil exchangeable plant-available Al levels, have been confounded by other controlling factors. A survey of topsoil depth at this site revealed large differences over short distances. Further, the only indice which relates to our yield measurements, to date, was topsoil depth. Given that the finer textured topsoil sits over a very coarse gravel base of low readily (plant)-available water holding capacity (RAWC), it is likely that variation in micro-topography, influencing topsoil depth, is strongly affecting plant yield by substantially increasing the RAWC of the deeper fine textured soil compared with an area with a shallow topsoil (Brown *et al.* 2003; 2009). The rainfall at this site is also low (≈600 mm/yr), especially over summer. Therefore, the variable topsoil depth, in combination with a summer-dry climate, appear to be the key factors driving lucerne yield. Yields do not appear to be related to pH and Al levels. However, this is an establishing crop, and any effect may become apparent over the next 12 months. This result reinforces the importance of running trials for longer time spans in order to report on the effects of climate and its variability. It is also possible that soil pH and exchangeable Al levels are in fact reducing lucerne rooting depth (observed visually), and therefore effective plant water availability. Further work is to assess the feasibility and economics of liming.

Conclusions

- Soil pH was strongly related to levels of soil plant-available aluminium.
- Surface applied lime increased soil pH and reduced soil plant-available aluminium.
- Liming was most effective at the soil surface and less effective at depth (15-30 cm).
- Higher rates of lime were more effective, though data were variable. No significant difference in effectiveness between 'AgLime' and 'Quicklime' was detected.
- Soil pH and Al levels were not related to lucerne yield. Extreme variability in depth of topsoil (micro-topography) and hence plant-available water storage have influenced yields.

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REFERENCES

Black, A.S.; Cameron, K.C. 1984. Effect of leaching on soil properties and lucerne growth following lime and gypsum amendments to a soil with an acid subsoil. *New Zealand Journal of Agricultural Research 27*: 195-200.

Brown, H.E.; Moot, D.J.; Fletcher, A.L.; Jamieson, P.D. 2009. A framework for quantifying water extraction and water stress responses of perennial lucerne. *Crop and Pasture Science 60*: 785-794.

Brown, H.E.; Moot, D.J.; Pollock, K.M. 2003. Long term growth rates and water extraction patterns of dryland chicory, lucerne and red clover. *Legumes for dryland pastures. Grassland Research and Practice Series 11*: 91-99.

Edmeades, D.C.; Smart C.E.; Wheeler, D.M. 1983. Aluminium toxicity in New Zealand soils: preliminary results on the development of diagnostic criteria. *New Zealand Journal of Agricultural Research 26*: 493-501.

Edmeades, D.C.; Blamey, F.P.C.; Asher, C.J.; Edwards, D.G. 1991. Effects of pH and aluminium on the growth of temperate pasture species. II. Growth and nodulation of legumes. *Australian Journal of Agricultural Research 42*: 893-900.

Fasi, V.; Mills, A.; Moot, D. J.; Scott, W. R.; Pollock, K. 2008. Comparative growth forms of dryland forage legumes. *Proceedings of the New Zealand Grassland Association 70*: 123-130.

Grewal, H.S.; Williams, R. 2003. Liming and cultivars affect root growth, nodulation, leaf to stem ratio, herbage yield, and elemental composition of alfalfa on an acid soil. *Journal of Plant Nutrition 26*: 1683-1696.

Haynes, R.J.; Williams, P.H. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in Agronomy 49*: 120-199.

Hochman, Z.; Edmeades, D.C; White, E. 1992. Changes in effective cation exchange capacity and exchangeable aluminium with soil pH in lime-amended field soils. *Australian Journal of Soil Research 30*: 177-187.

Lanyon, L.E.; Griffith, W.K. 1988. Nutrition and fertilizer use. pp. 333-372. *In:* Alfalfa and alfalfa improvement. Eds. Hanson, A.A.; Barnes, D.K.; Hill, R.R. American Society of Agronomy, Madison, USA.

Lewis, B. 2007. Understanding how sowing rate and date affect autumn lucerne establishment in Canterbury. Unpublished Bachelor of Agricultural Science Honours dissertation, Lincoln University, New Zealand.

McGowan, A.W.; Sheath, G.W.; Webby, R.W. 2003. Lucerne for high quality summer feed in North Island hill country. *Legumes for dryland pastures. Grassland Research and Practice Series 11*: 169-174.

Moir, J.L.; Scotter, D.R.; Hedley, M.J.; Mackay, A.D. 2000. A climate-driven, soil fertility dependent, pasture production model. *New Zealand Journal of Agricultural Research 43*: 491-500.

Mullen, C.L.; Scott, B.J.; Evans, C.M.; Conyers, M.K. 2006. Effect of soil acidity and liming on lucerne and following crops in central-western New South Wales. *Australian Journal of Experimental Agriculture 46*: 1291-1300.

Rechcigl, J.E.; Edmisten, K.L.; Wolf, D.D.; Renau, R.B. Jr. 1988. Response of alfalfa grown on acid soil to different chemical amendments. *Agronomy Journal 80*: 515-518.

Su, C.; Evans, L.J. 1996. Soil solution chemistry and alfalfa response to $CaCO_3$ and $MgCO_3$ on an acidic gleysol. *Canadian Journal of Soil Science 76*: 41-47.

Teixeira, E.I.; Moot, D.J.; Brown, H.E.; Fletcher, A.L. 2006. The dynamics of lucerne (*Medicago sativa* L.) yield components in response to defoliation frequency. *European Journal of Agronomy 26*: 394-400.

Thomas, R.G. 2003. Comparative growth forms of dryland forage legumes. *Legumes for dryland pastures. Grassland Research and Practice Series No.11*: 19-25.

Wheeler, D.M.; Edmeades, D.C.; Christie, R.A.; Gardner, R. 1992. Effect of aluminium on the growth of 34 plant species: A summary of results obtained in low ionic strength solution culture. *Plant and Soil 146*: 61-66.

Wheeler, D.M.; Edmeades, D.C. 1995. Effect of depth and lime or phosphorus fertilizer applications on the soil solution chemistry of some New Zealand pastoral soils. *Australian Journal of Agricultural Research 33*: 461-476.