The effect of two lime sources on short-term changes in soil pH under Marlborough hill country pasture

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Abstract

The effect of fine slurried lime applied at 200 kg/ha on soil pH at two depths was compared with 400 and 2500 kg/ha of local agricultural (ag) lime in the presence and absence of sulphur (S) superphosphate 20, in Marlborough hill country for one year. In the absence of fertiliser all lime treatments significantly raised soil pH in the top 25 mm for the 355 days after application. Initial responses declined from day 14 or 35 to day 138 before increasing at day 355. Fine lime did not significantly alter pH in the 25-75 mm zone until day 355. The low rate of ag lime significantly raised pH in the 25-75 mm zone for the whole year. The high rate of ag lime significantly increased pH in the top 25 mm over the other lime treatments for the 355 days and over the fine lime treatment in the 25-75 mm zone from day 35. In the presence of fertiliser in the top 25 mm, fine lime significantly increased pH at day 14 only, and low ag lime at day 355 only. The high rate of ag lime significantly increased pH over the control from day 14 and over the other lime rates from day 35. In the 25-75 mm zone the high rate of ag lime significantly increased pH over the control and the low ag lime rate from day 71 but was significantly better than fine lime from day 35. It is likely that rain immediately after application and higher than average annual rainfall hastened the release of fine and intermediate particles of lime. However provided lime meets the accepted criteria for particle size distribution and maximum size it is the rate of application which dictates the magnitude of response. In Marlborough hill country it was 43% cheaper to aerially apply 400 kg/ha of ag lime compared to 200 kg/ha of fine lime with the added benefit of a greater residual effect beyond one year.

Keywords: agricultural lime, fine lime, slurry, soil pH

Introduction

Agricultural lime has been used for many years on mineral soils in New Zealand as a means to increase soil pH. Typical rates are 2500 kg/ha with reapplication every 3-10 years (depending on rainfall) to maintain pH's of 5.8-6.2. However responses to lime are often quite varied (Edmeades *et al.* 1984). There are several reasons for this, increasing pH to these levels, can lead to improved microbial activity and nitrogen (N) and phosphorus (P) availability which in turn leads to improved pasture, in particular legume production and hence animal performance (Edmeades *et al.* 1985). Liming also improves Mo availability resulting in better legume performance, although this can sometimes induce copper (Cu) deficiency in livestock. On some soils at low pHs, (<5.5), liming can reduce plant availability of aluminium (Al) and manganese (Mn) which would otherwise impair legume performance (During 1984; Edmeades 2000). It is also believed lime can improve soil moisture availability on drier soils (During 1984).

Many hill country soils including those in Marlborough are known to be responsive to liming and/or Mo (During 1961; 1984). However hill country has not been extensively limed because of the cost of applying high rates by aerial application. Previous work has shown it is the rate of lime applied and the initial pH that dictates the longevity of a response (Edmeades *et al.* 1981), which coupled with the calcium carbonate content and particle size, affects the economics of using lime (Shannon 1999). Liming decisions now also reflect the size and duration of a dry matter (DM) response or pasture performance in relation to the increase in animal performance and revenue the animal enterprise generates (Cornforth & Sinclair 1984; Edmeades *et al.* 1985). Using this approach it could be economic to lime hill country at lower than conventional rates to maintain pH's lower than 5.8. In one study on sedimentary hill soils in the North Island, it was economic to apply 1250 kg/ha of lime (O'Connor *et al.* 1981) and it is becoming popular for farmers to apply rates of 400-500 kg/ha on a more frequent basis.

An alternative approach to using lower rates of ag lime has been to use lime of sufficient fineness that it can be slurried in water and applied by fixed wing aircraft. This product has been extensively promoted in Marlborough, the rationale being that the coarser fractions of ag lime take too long to dissolve so are not very useful. Therefore by using a fine lime flour which is immediately available, rates of lime could be significantly reduced. Typical rates vary from 100-300 kg/ha applied every 12-36 months (Rainham pers. comm.). It is claimed this product generates higher pHs and is more cost effective than ag lime, although there is no scientific basis for these claims. Fine lime has also been claimed to be more effective than fertiliser, and although this could be due to a P-sparing effect of lime that can occur in some situations (Mansell *et al.* 1984) it fails to address longer term P needs and that of S. The concept of slurrying lime does have some benefits as it could provide more even coverage and overcome dust problems and bridging difficulties associated with trying to get an even spread of ag lime from an aircraft hopper (Pratt *et al.* 2005).

To assist with lime recommendations in Marlborough and help clarify some of these claims a small replicated trial was laid down in Marlborough hill country to compare in the presence and absence of fertiliser, the effect of fine lime and two rates of ag lime on soil pH at two depths over a twelve month period.

Materials and methods

Site

The site was located at 'The Brothers' in the Wairau Valley, Marlborough, 1.5 km east of Wairau Valley township, on a north (sunny) facing Wither Hill soil, classified as a Yellow Grey Earth or Pallic soil (Hewitt 1992). The site was in a 32 ha oversown hill block very drought prone in summer and with a past irregular fertiliser history of S fortified supers. The pasture consisted of a mixture of improved ryegrass and white clover with browntop, sweet vernal and subterranean and suckling clovers. The block was used for sheep and cattle grazing. The soil test for the site was; pH 5.3, Olsen P 12 ug/ml, MAF quick test calcium (Ca) 5, potassium (K) 6, magnesium (Mg) 34 and sulphate-S 6 ug/g. Exchangeable aluminium (Al) was 3.4 mg/kg ($CaCl_2$ extraction) indicating a marginal toxicity to legumes (Edmeades *et al.* 1983). The site was known to respond to P and S (Craighead 2004; Craighead unpublished data).

Treatments

Treatments were: nil lime control, 200 kg/ha of Taylor's fine lime, 400 kg/ha and 2500 kg/ha of ag lime. Taylor's fine lime was Ngarua (Takaka Hill) lime ground locally at Spring Creek by Midland Distributors as used by the local aerial contractor for slurrying with water. The rate was typical of that used at the time. This was added to sufficient water to spread. The local ag lime came from the Clarence Valley Lime Company in Southern Marlborough. The particle size analysis of both products is given in Figure 1. The low rate of ag lime applied was chosen to give a similar amount of fine material as the fine lime treatment. As it was impossible to exactly mimic the particle size distribution of the Taylor's fine lime due to its fineness (91% below 0.075 mm), it was assumed that all lime particles < 0.25 mm and approximately 60% of the 0.25-0.5 mm size would be available quickly from the Clarence Valley lime. After also allowing for the higher $CaCO_3$ content in the Taylor's fine lime (98.6 vs. 87.9%), the low rate of Clarence Valley lime was set at 400 kg/ha. The high ag lime rate corresponded to a more traditional lime dressing. Both ag lime treatments were applied as dry fertiliser and the liming materials contained 0.8% and 1.3% moisture (fine lime and ag lime respectively).

The trial consisted of main plots with and without fertiliser, with subplots consisting of the lime treatments. Each was replicated three times in a randomised block design, so in total there were 24 subplots. The fertiliser consisted of 188 kg/ha of S super 20, containing half its S (10%) as elemental S (S^O). This was a typical biennial application rate for the district. This rate almost meets maintenance P and S requirements for 7-8 SU/ha had the site been grazed, as calculated from a modified version of the MAF CFAS programme of Cornforth & Sinclair (1984). Each subplot was 2 m^2 in size (2 m x 1 m) and each plot was separated by a buffer zone. Treatments were applied on 24th June 1998 and soil pH measurements continued until 15th June 1999. In total measurements were taken six times with the frequency extending with time, as outlined in Table 1. At each harvest, 8 cores were taken from each subplot, (avoiding sampling the top 30 cm of each plot) and split into 0-25 mm and 25-75 mm samples for analysis.

Figure 1 Lime particle size (mm) of Taylor's fine lime and Clarence Valley agricultural lime, Marlborough.

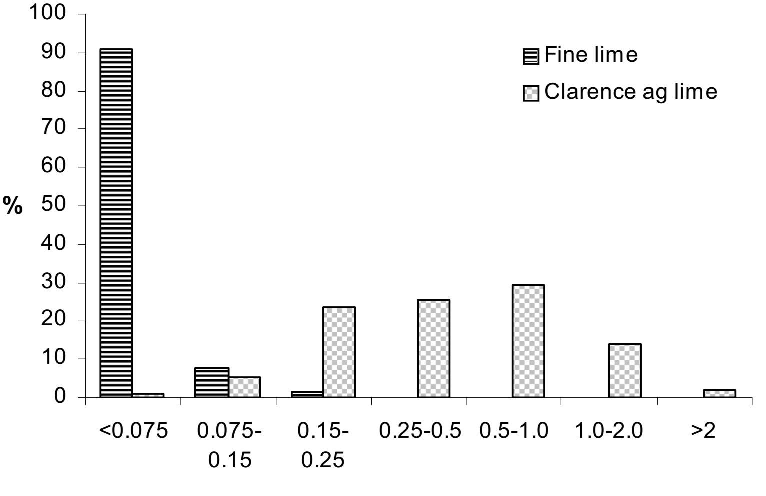


Table 1 Site rainfall data (June 1998-May 1999).

Date	Sample	Day	Rainfall (mm)	Accumulated rainfall (mm)
24/6/98	H1	0	0	0
9/7/98	H2	14	120	120
30/7/98	H3	35	41	161
4/9/98	H4	71	92	253
5/10/98			70	323
22/10/98			154	477
10/11/98	H5	138	50	527
1/12/98			28	555
22/12/98			59	614
9/2/99			67	681
4/5/99			169	850
16/6/99	H6	355	not measured	850+

The site was fenced from grazing and lightly trimmed as required (four times from late-winter to early-summer) with 40% of the clippings returned to the area to approximate grazing. Potassium chloride (20 kg K/ha) was applied at the beginning to account for losses associated with herbage removal. Soil pH was measured on air dried soil, using 10 or 20 g of soil in 25 or 50 ml of water, after mixing and leaving for 4 hours with intermittent stirring before measurement using an Orion pH electrode. Rainfall was regularly measured each time the site was visited.

Results

Rainfall data is given in Table 1. It rained lightly at the time of application and in the following 14 days rainfall was high with water noted running down the plots. Some coarser fractions from the high rate of ag lime were still evident at harvests 2 and 3. Following good spring rains the site became drier and remained that way over summer until autumn rain fell. Annual rainfall was higher than normal (six year average 1988-1994 for a site 500 m away but slightly lower altitude was 660 mm). However the low summer rainfall was very typical as was the high October rainfall, as invariably in early summer the district receives a high rainfall event.

Background 'control' pH

The initial pH of the site was 5.21 in the top 25 mm of soil and 5.17 in the 25-75 mm zone. Both increased during the year peaking in September (H4) at 5.42 and 5.31 respectively before slightly declining by June 1999 (H6) to 5.26 and 5.19 respectively. To account for this change in background pH, the data for each lime treatment in the presence and absence of fertiliser is presented as the change in pH from the 'control' pH at that harvest.

Lime only effects

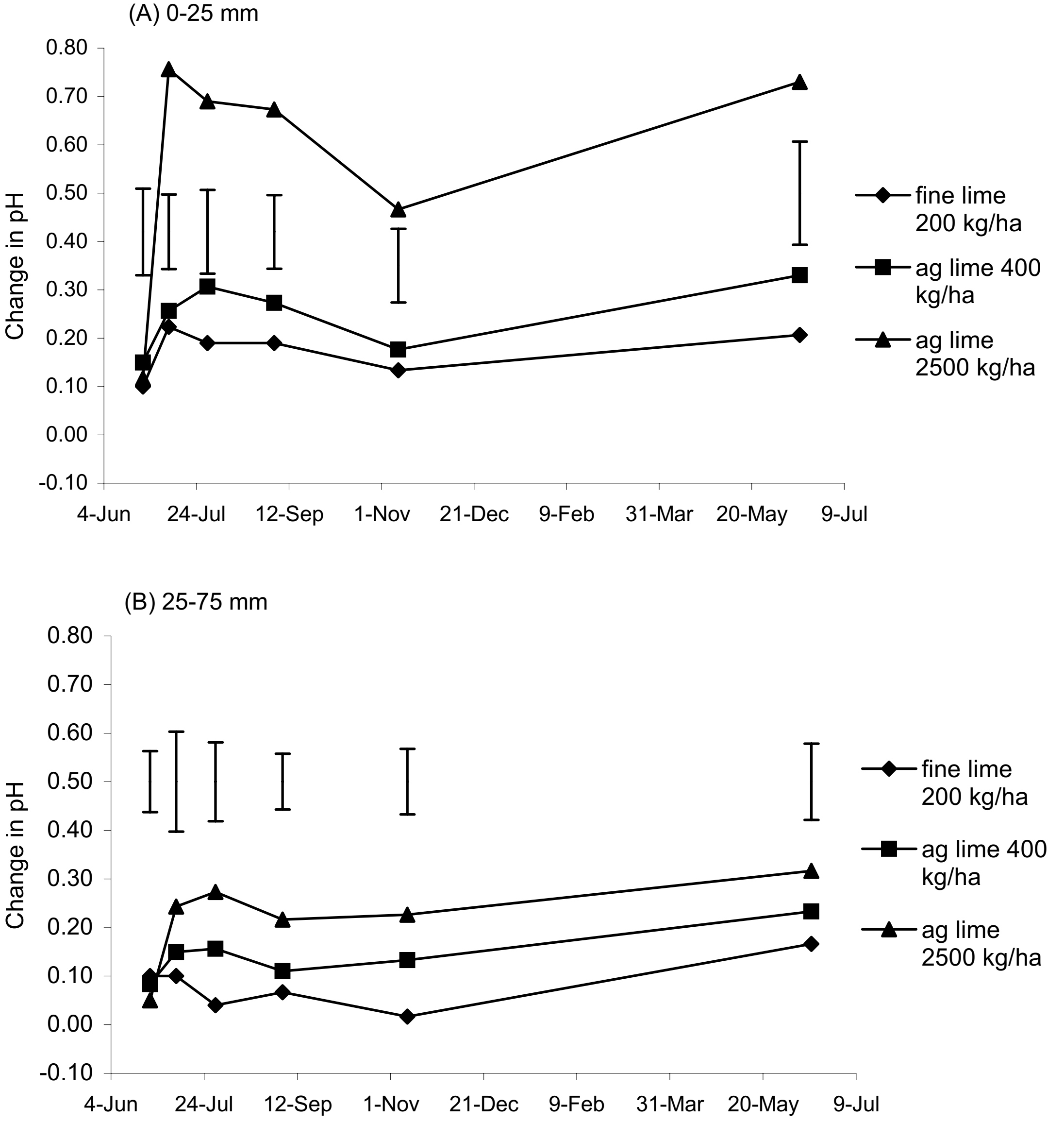
In the absence of fertiliser, soil pH in the top 25 mm (Figure 2a) significantly increased ($P < 0.05$) immediately after lime application (H2) at all lime rates. All treatments remained significantly above the control for the 355 days. However by day 14 (H2) the fine lime and the high rate of ag lime had reached their maximum initial effectiveness whereas the low rate of ag lime took until day 35 (H3) to reach its maximum initial effectiveness. All lime rates declined in effectiveness from day 35 to day 138 (H5) before rising again at day 355, the final harvest (H6). Although there was an overall trend for the low rate of ag lime to increase pH over the fine lime this was not significant at each harvest. By contrast, the high rate of ag lime significantly increased soil pH for the 355 days compared to the other lime treatments.

In the absence of fertiliser in the 25-75 mm zone (Figure 2b), the response was smaller but the trend similar to those in the top 25 mm for all treatments with the maximum change in pH occurring at day 355. Fine lime did not significantly lift pH above the control until the last two harvests (from day 138). By contrast the two rates of ag lime significantly increased pH over the control from day 14 with the high rate of ag lime significantly better than the fine lime from day 35. At no time did the high rate significantly change the pH compared to the low rate of ag lime ($P < 0.05$) nor did the low rate cause significant change compared to the fine lime.

Lime with fertiliser effects

In the presence of fertiliser the trends were similar to those without fertiliser but of a lower magnitude. In the top 25 mm of soil (Figure 3a), fine lime significantly increased pH at day 14 only. The low rate of ag lime did not significantly lift pH over the control until day 355 and at no time over the fine lime. The high rate of ag lime

Figure 2 Change in top 25 mm pH (A) and 25-75 mm soil depth (B) 1998-99 following lime application. Bars represent $LSD_{5\%}$ between treatments, $LSeffect_{5\%}$ for comparison with no lime control = $LSD_{5\%}$ x 0.7.



significantly changed pH over the control from day 14 and the two low rates of lime from day 35.

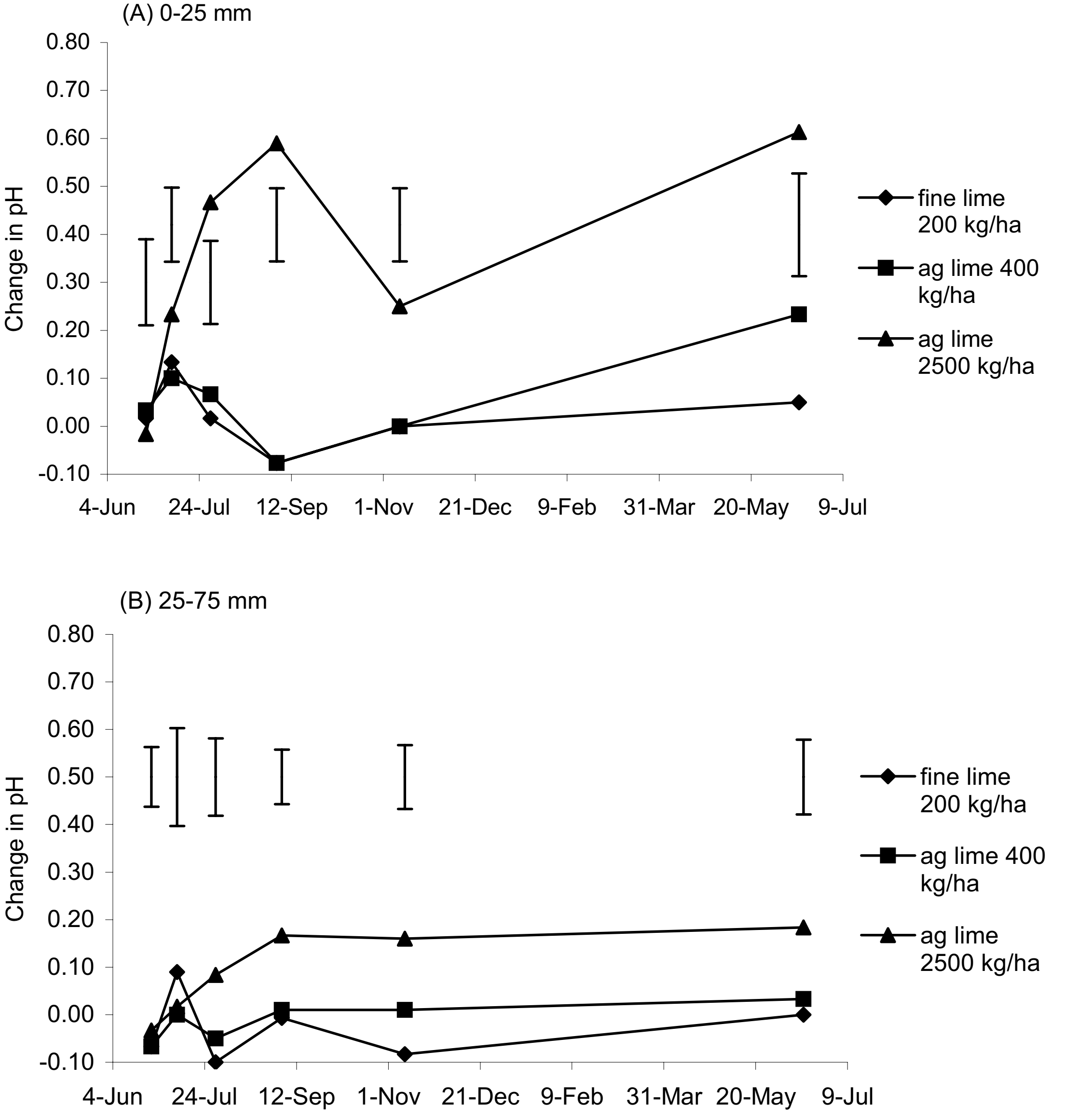
In the presence of fertiliser in the 25-75 mm zone (Figure 3b), only the high rate of ag lime significantly increased soil pH and then only from day 71 onwards. The high rate of ag lime significantly changed pH over the low rate of ag lime from day 71 and fine lime from day 35 as fertiliser caused short term depressions in pH at this depth, it taking the fine lime treatment the full 355 days to overcome these.

There was little interaction between individual lime treatments and fertiliser, except at day 14 when fertiliser significantly ($P = 0.004$) lessened the pH change caused by the high rate of ag lime in the top 25 mm.

Discussion

In this study, rainfall immediately after application ensured ideal moisture conditions for lime dissolution. With the slurried fine lime treatment this was reflected in an immediate increase in 0-25 mm pH irrespective of whether fertiliser was also applied. This effect was short lived, as given the fineness of the lime most would be

Figure 3 Change in top soil pH (A) and 25-75 mm soil depth (B) 1998-99 following lime application in the presence of 188 kg/ha S super 20. Bars represent $LSD_{5\%}$ between treatments, $LSeffect_{5\%}$ for comparison with no lime control = $LSD_{5\%}$ x 0.7.



expected to release immediately after application. Despite good October rains encouraging movement down the profile, significant change in pH was not observed beyond 25 mm until day 355 and then only when no fertiliser was applied. Mixing of topsoil and subsoil, due to earthworm activity is not high on this soil due to the low fertility nature of this site. Therefore any benefits attributable to the fine lime on earthworm activity is likely to be small due to the small change in pH.

Agricultural lime at 400 kg/ha achieved the same initial lift in pH (0-25 mm) as the fine lime despite being coarser and of lower $CaCO_3$ content. This indicates some of the particles > 0.075 mm must have been quickly available, with slightly larger particles ensuring a more prolonged response over the next two harvests, some of which raised the pH beyond 25 mm when fertiliser was not also applied. As 400 kg/ha of ag lime performs slightly better than 200 kg/ha of fine lime for the whole season this suggests the assumption that all particles < 0.25 mm and 60% of those 0.25-0.5 mm are available within the first year from this lime is if anything conservative. Its coarser fractions have allowed for a greater residual effect in time over the whole 75 mm. Although rainfall was above average, particularly early in the trial this is more likely to hasten dissolution in the short to intermediate term rather than for the whole year as the summer was still typically dry. Annual rainfall of < 900 mm is still considered low compared to most hill country in NZ. To significantly and more quickly change pH over an extended period and depth there is no substitute for traditional (high) rates of ag lime. In this study when ag lime was applied at 2500 kg/ha sufficient moved below 25 mm within 14 days to significantly increase pH, and within 35-71 days (depending on whether fertiliser was also applied) to be significantly better than the lower rate of ag lime. As pasture plants root below 25 and indeed 75 mm it is necessary to alter pH over the whole root zone. Low rates of lime, in particular 200 kg/ha of fine lime cannot adequately do this. This result suggests that provided agricultural lime meets the accepted criteria for NZ lime of 50% < 0.5 mm, 95% < 2 mm and > 70% purity (Shannon 1999) then sufficient will dissolve in soil solution to quickly raise the pH in the top 75 mm. Previous NZ trials where different rates of lime have been used have also shown that soil pH (0-75 mm) increases with increasing rate of lime applied (Edmeades *et al*. 1981; O'Connor & Hunt unpublished data). In this study with ag lime the uneven particle size distribution and hence delayed release of intermediate fractions may account for the drop-off in response at harvest 5 (day 138) and the subsequent lift at day 355. Coarser fractions normally takes 12-18 months to reach maximum effectiveness (Edmeades 2000). However this does not adequately explain the lift at day 355 from the fine lime which has no coarse fractions. One reason for this may be because liming also assisted in the rewetting of the soil after the dry summer and autumn rain may have improved subsequent anion, e.g. nitrate uptake thereby increasing the pH relative to unlimed plots (During 1984; Sinclair *et al*. 1993).

Acidification

Sulphur super 20 reduces the impact lime has on pH because a portion is required to neutralise the oxidation of the S^O in the product. It requires 2.3 kequivalents or 110-115 kg/ha of $CaCO_3$ to neutralise the effect of 188 kg/ha of Sulphur Super 20 (Sinclair *et al.* 1993). Hence it is understandable why it took so long for low rates of lime to increase pH in the presence of fertiliser, with even a short term effect on the high rate of lime. In the 25-75 mm zone, fine lime is probably more effective than ag lime in the short term as some can dissolve and move quickly to immediately neutralise the oxidation of the finest fractions of S^O at this depth.

Lime is also required on hill country to neutralise the soil acidification caused by animal grazing (Sinclair *et al*. 1993). In hill country, carbon fixation whereby pasture is consumed but unevenly redistributed as excreta to stock camp areas is the main acidifying source. Together with acidification caused by N leaching under in particular cattle urine patches, it should require 0.3-0.4 kequivalents of lime or 15-20 kg of Ca CO_3/SU to neutralise this acidity (Sinclair 1995). Therefore 130-140 kg/ha of fine lime or 150-160 kg/ha of Clarence Valley ag lime is required to support 7-8 SU/ha, if no S^O was applied. The latter is not a viable option in this country as responses to S super 30 in a previous trial (Craighead unpublished data) have shown a 50% DM response over four years. The lime model of Edmeades *et al*. (1985) would suggest at this site pH (5.2-5.3), DM responses to lime would be < 6%. Although there appears little economic justification in lifting the pH above 5.4-5.6 for a sheep and cattle enterprise (Edmeades 2000), it could be argued any lime treatment that can lift pH by 0.1-0.2 might be justified. On this site annual maintenance fertiliser is approximately 100 kg/ha of Sulphur Super 20 requiring 50-60 kg $CaCO_3$ in addition to the 130-140 kg/ha of fine lime previously described to neutralise soil acidification processes. An annual application of 200 kg/ha of fine lime could meet this, but as it barely changes the pH by 0.1 after one year (based on the mean 0-75 mm response at day 355 at both fertiliser regimes) it might have difficulty in maintaining pH in the long term especially in the years where topdressing occurs. Annual acidification will be neutralised by using 400 kg/ha of ag lime as this almost gave a mean 0.2 pH increase after one year. These responses are greater than those observed by O'Connor & Hunt (pers. comm.) on clay hill soils in Northland where lime rates below 1000 kg/ha had little effect on soil pH after one year. Some differences might be expected as their site had higher lime requirements due to a higher rainfall, clay content and pasture production while the lime used was of a lower quality (71% $CaCO_3$). Results from this Marlborough study do not reflect pH changes beyond 355 days, these are likely to be important at low lime rates where S^O is applied, as only a portion, (< 40%) would have mineralised within the first year (Boswell & Swanney 1988; Craighead 1997). This means residual acidifying effects will be present on any hill country property previously receiving S^O. This may partly account for the variability noted in the initial pH's in this study.

Despite the small increases in soil pH low rates of lime achieve they might also be beneficial in the oversowing of hill country or in the reseeding of pasture. Agricultural lime at 625 kg/ha was beneficial in grass establishment in bracken country without affecting clover establishment, the response attributed to stimulating N release from organic matter (During 1984). As establishment is a short term proposition a lime product containing more fines than conventional ag lime may also be more useful assuming acidifying fertilisers are also applied in the development phase. Several lime companies produce such products.

Economics

Fine lime is more expensive than ag lime. The applied cost of 200 kg/ha of Taylor's fine lime (product cost $110/t) on this property is approximately $60/ha. This compares to $42/ha to apply 400 kg/ha of Clarence Valley lime (product cost $22/t). This represents a 43% saving (or 29% if the difference in lime quality is factored in). However as the Clarence Valley lime at this rate has greater residual effects the savings are more realistically 50-80%. In other areas of Marlborough greater savings are likely as in the Awatere Valley, the Upper Wairau Valley and the Rai Valley lower transport costs for ag lime or higher quality lime sources can be used. Similar comparisons of Taylor's fine lime (which is sold nationally) can be made with locally sourced limes in other areas of NZ.

This work did not address any concerns over the evenness of spread of solid lime which slurrying fine lime may overcome. An alternative increasingly popular overseas is to granulate fine lime (Blake 1999). A North Canterbury company, CP Lime Solutions now produces such a product but it is not currently a cost effective alternative (at $190/t) compared to applying low rates of ag lime.

Conclusions

- In Marlborough hill country over 355 days fine lime at 200 kg/ha generally only significantly increased pH in the top 25 mm rather than 75 mm of soil and then in the absence of acidifying fertiliser.
- 400 kg/ha of local ag lime was sufficient to lift and hold pH for at least one year in the top 75 mm of soil, although the effect was less and took longer when acidifying fertiliser was also applied.
- 2500 kg/ha of local ag lime gave significantly higher soil pH's than the other lime treatments in the top 75 mm of soil irrespective of whether fertiliser was used and would therefore have a greater residual effect.
- Providing a lime meets the accepted lime particle size criteria (50% < 0.25 mm, 95% < 2 mm), it is the application rate of the lime that dictates the effectiveness of lime in raising soil pH.
- The economics of lime use in Marlborough hill country needs to be addressed on an individual farm basis once maintenance fertiliser requirements have been met. If low rates of lime are to be used the rates have to be sufficient to address maintenance lime needs. Four hundred kg/ha of ag lime was a cheaper and more efficient alternative to 200 kg/ha of fine lime slurry to address this.

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