The effects of lime on pasture composition and production in western Waikato hill country

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Abstract

A 4-year lime rate trial was established on a hill country sheep and cattle property near Te Akau to determine lime effects on pasture utilisation. Four rates of lime were applied (1.25 t/ha, 2.5 t/ha, 5 t/ha and 10 t/ha) to 2 m × 2 m plots, from which soil Al, Ca and pH, pasture grazing heights, dry matter production, pasture species composition, feed quality and brix levels were measured. Lime application reduced soil Al (14.6 to 1.1 mg/kg), and increased Ca and pH (5.0 to 6.2) over time in the highest application rate. Dry matter production responded to all rates of lime in each year, and by the fourth year it was 27% greater (1.25 t/ha treatment), 35% greater (2.5 t/ha treatment), 69% greater (5 t/ha treatment), and 97% greater (10 t/ha treatment) than in the un-limed plots. Ryegrass and subterranean clover content increased with lime rate, whereas chewings fescue and dicot weed content declined. There were no sustained differences in pasture grazing heights, feed quality or brix levels between the control and rates of lime. On this site, all rates of lime were economic to apply by truck or plane when the benefits were spread over 4 years, with the greatest cost-benefit from the lower rates of lime.

Keywords: herbage accumulation, soil aluminium, soil pH

Background

Some hill country farmers who have applied lime in the Waingaro and Te Akau areas have observed that pasture utilisation improves and that there is much less rank, stalky dead matter as a result of the more consistent grazing. They have suggested that the lime ‘sweetens’ the grass, making it more palatable to livestock. This district in western Waikato is known for mild winters and dry summers, with excessive stalky material on hillsides which stock often avoid grazing until winter (Sheath & Boom 1985). Anecdotal reports indicate improved palatability of limed pastures (Woodcock 1935). Toxopeus (1989) noted that ‘the palatability of the limed plots is generally better as shown in grazing’. If it could be shown that applying lime improves pasture utilisation, this is an opportunity for farmers to convert excess pasture grown over the summer into useful stock feed and thereby make the application of lime a more attractive fertiliser option for hill country farmers to consider.

Lime responses in pasture have been attributed to amelioration of aluminium (Al) and manganese (Mn) toxicity, increased plant availability of nitrogen (N), phosphorus (P) and molybdenum (Mo), and increased soil moisture (Wheeler & O’Connor 1998). Lime trials on North Island hill country have often shown poorer dry matter (DM) responses compared to application of P fertiliser (Karlovsky 1973); therefore, there has not been an emphasis on applying lime on hill country due to the high cost of flying bulk quantities of lime on by plane. For example, with a pH of 5.0, pasture responses to lime commonly range from 8-12% (Roberts et al. 1996), but 8-10 t/ha of lime would be required to lift the pH into the biological optimum range of 5.8-6.0 for ryegrass/clover pasture. Edmeades et al. (2016) argued that it is normally economic to ground-spread lime to this biological optimum level, but with the extra costs for aerial application the optimum target pH should be 5.5-5.6 on hill country.

Aluminium toxicity extends across many soil orders and climatic zones with brown soils showing the highest Al concentrations (Whitley et al. 2016). Recent research has focussed on the importance of lime on South Island hill and high country to mitigate Al toxicity for legume establishment and persistence (Moir et al. 2018). These authors also noted the need for more information to understand the implications of Al toxicity, which has become a serious issue for pastoral farming in New Zealand. Although lime is the main tool used for ameliorating Al toxicity and low pH issues, other tools such as Al-tolerant grasses like cocksfoot (*Dactylis glomerata* L., Wheeler et al. 1992) and legumes such as lupins (*Lupinus* spp.) and Caucasian clover (*Trifolium ambiguum* M.Bieb., Wheeler & Dodd 1995), or carboxylate co-polymer AlpHa (Bishop & Quin 2013) could be considered. Perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) are very sensitive to Al toxicity, whereas subterranean clover (*Trifolium subterraneum* L.) is slightly more tolerant (Edmeades et al. 1991). Thus, any amelioration by lime might be expected to lead to a long-term shift

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in botanical composition in mixed swards. However, Al-tolerant pasture species have shown no significant responses to lime at low pH (5.1) and high Al levels (17.5 $CaCl_2$-extractable, Stevens et al. 2014).

This trial was instigated by a group of local Waikato hill country farmers who had observed marked changes in their pastures and stock grazing preferences following lime applications and were keen to obtain data and insight into why this was so apparent. The objective was to determine the effect of a range of lime rates, from a single application, on the herbage accumulation, botanical composition and herbage quality of long-term resident hill country pastures.

Approach

Site characteristics

A site was selected on a Brown soil (Te Ranga) on Piquet Hill Farm near Te Akau, western Waikato (Lat. -37.686, Long. 174.893), on a part of the property which had no known previous applications of lime and where P applications had been minimal, resulting in levels less than half the biological optimum at the beginning of the trial. The trial site was an evenly contoured east-facing hillside averaging 16-degree slope which livestock had historically avoided grazing hard over summer-autumn. The trial site was a small area within a large paddock (17 ha) and was grazed as normally by the farm owner, which involved set-stocking over the spring period with sheep followed by intermittent rotational grazing over the summer and autumn with sheep and cattle.

Initial soil test results revealed low pH (5.0) and a high $CaCl_2$-extractable Al level (14.6 mg/kg) and an Olsen P of 9 ppm. Herbage tests showed there was neither Mn toxicity nor Mo deficiency on this trial area.

Trial Design and Measurements

The trial comprised treatments of five rates of lime (nil control, 1.25 t/ha, 2.5 t/ha, 5 t/ha and 10 t/ha) arranged in four randomized complete blocks with plot dimensions of 2 m × 2 m. Lime was sourced from a local commercial outlet and applied to plots on 1 July 2015.

Soils were sampled at 0-75 mm depth from each plot in winter each year and replicate plot samples were bulked for analysis of $CaCl_2$-extractable Al, Quicktest Ca and pH (Edmeades et al. 1983; Blakemore et al. 1987). Note that this means no statistical analysis of soil effects was possible, but establishes the effect of the lime treatments on key soil characteristics. In the final year samples from 75-150 mm depth were also taken for the same analyses.

A cage (0.5 m × 0.25 m) was placed over each plot to exclude grazing and DM cuts to a height of 1 cm were taken 4 or 5 times each growing season (July-June) using the double trim cut technique (Radcliffe et al. 1968) over 4 years. Harvested material was oven-dried (85°C for 24 hours) and weighed for DM determination. Fresh pasture samples were taken alongside each harvest for dissections into individual species, except for non-legume dicot weeds and dead matter which were bulk categories. Sub-samples of the oven-dried material were analysed for elements (N, P, K, S, Ca, Mg, Na, B, Fe, Mn, Cu, Zn) and feed quality (crude protein, metabolisable energy (ME), organic matter digestibility (OMD), acid digestible fibre (ADF) and neutral detergent fibre (NDF)) using standard laboratory methods (Givens et al. 2000).

Each time pasture cuts were taken, pasture canopy grazing heights were measured using a pasture sward stick placed randomly at 25 positions within the uncaged part of each plot.

Brix tests were taken on each plot at each harvest during the first year. This rapid field test measures the water-soluble-compound content of the sap, extracted from plant tissue by hand rolling and squeezing in a garlic press and measurement in a refractometer (Balsom & Lynch 2008). The brix measurements were discontinued after the first year as the readings showed no consistent trends between treatments, and the grazing canopy height measurements were discontinued for the final year.

Each winter, a pasture species survey using point intercept analysis (Levy & Madden 1933) was undertaken to determine botanical composition differences. For each plot, 25 points were selected with all intersects through the canopy recorded for each point; percentage cover was calculated in 4% increments.

Statistical analyses

Herbage accumulation and botanical composition data were analysed by analysis of variance (ANOVA) in Genstat Edition 18 (VSN International 2020), including lime treatment and season as fixed effects and replicate as a block effect. Treatment means and error terms (Least Significant Difference) were generated where the main effects were significant in the ANOVA at $P<0.05$.

Results and Discussion

Soil effects

An increase in lime application rate resulted in a decrease in soil exchangeable Al and increases in Quicktest Ca and pH, all of which became more pronounced over the 4 years (Figure 1a,b,c). There were also noticeable increases in the cation exchange capacity (e.g., from 19 to 27 me/100 g), total base saturation (e.g., from 30 to 76%) and the base saturation percent of Ca (e.g., from 20 to 60%) , as would be expected with increasing rates of lime. It is unclear why the Al levels in the control plots decreased from 14.6 mg/kg to 7.8 mg/kg when the pH levels in Year 1 and Year 4 remained the same. There was also a similar decrease in exchangeable Al in the 1.25 t/ha treatment over time.

Olsen P levels remained consistent over all treatments ranging from 8 to10 ppm (data not presented), although there was a small decrease at the higher rates of lime as the P was either utilised faster due to pasture harvesting by grazing, or the higher rates of lime reduced the effectiveness of the Olsen P extraction method in the laboratory to detect P. In autumn 2018 the property received a capital application of P fertiliser resulting in an increase in Olsen P by an average by 6 units in the final year.

At the end of Year 4 there were some improvements in pH and Al levels at 75-150 mm depth with increasing rates of lime (Table 1), but the effects were not nearly as marked between treatments as those observed at 0-75 mm depth. At 75-150 mm depth there were negligible to no responses to 1.25 t/ha of lime compared to the control, and even the heaviest rate of 10 t/ha changed the chemistry little from what the 5 t/ha achieved. The results indicated that mitigation of Al toxicity occurred at higher rates of lime which was likely because of corresponding increased soil pH levels (Table 1).

Botanical composition

There was significantly greater abundance of perennial ryegrass with increas-

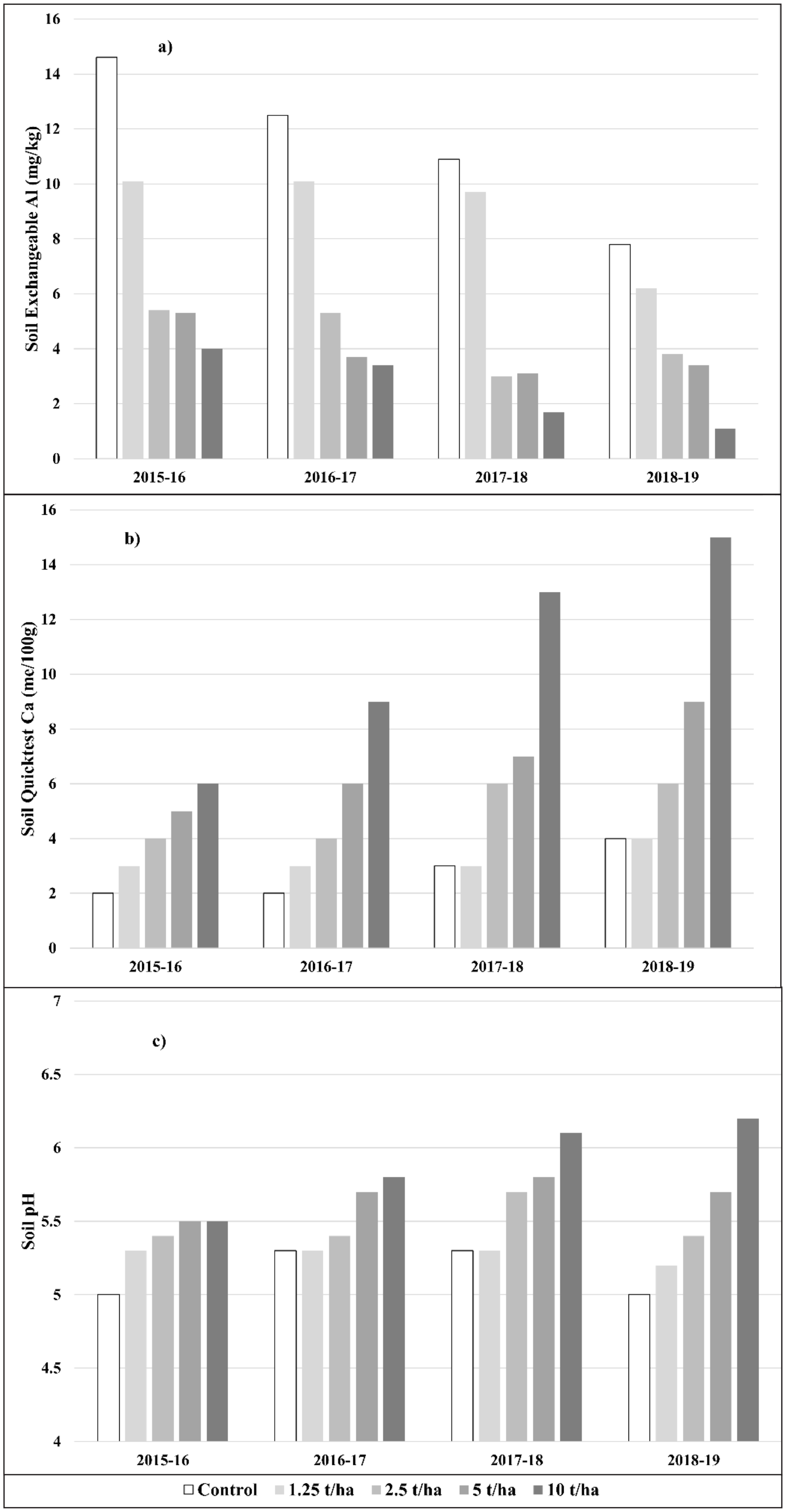

Figure 1 Effects of five lime rate treatments (t/ha) over four growing seasons on a) soil exchangeable Al, b) soil Quicktest Ca, and c) soil pH, for 0-75 mm soil depth.

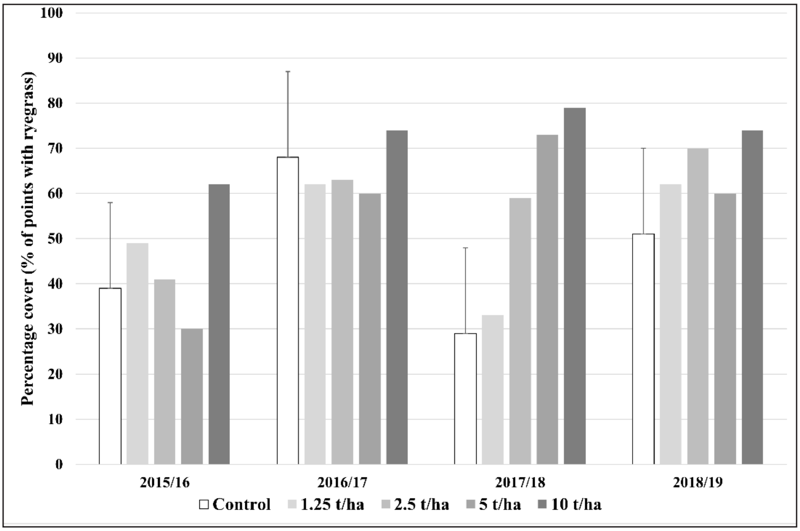

Figure 2 Perennial ryegrass cover (%) estimated from point intercept analysis in winter across five lime rate treatments and four growing seasons. Bars represent pooled LSD.

ing rates of lime for the third year, but not in other years (Figure 2; treatment × year interaction P<0.05). In the first and fourth years, only the 10 t/ha lime treatment had significantly more ryegrass hits than the control.

There were significant lime treatment and year effects on dicot weed abundance, with a reduction in dicotyledonous weeds at the higher lime rates (5 and 10 t/ha), particularly in the third year. This treatment by year pattern for dicot weeds was opposite to ryegrass, but the differences were not observed in the fourth year.

For white clover, slender trefoil (*Lotus angustissimus* L.) and other grasses, both main effects of lime treatment (P<0.05) and year (P<0.05) were significant, but there was no interaction. White clover abundance was greater (8% vs. 1-2%, P<0.01) and abundance of other grasses less (70% vs. 76-87%, P<0.05) in the 10 t/ha treatment compared to all other treatments. Slender trefoil abundance was greater in the 2.5 t/ha treatment (11%) compared to all other treatments (4-5%, P<0.01). White clover abundance was greater and other grass abundance less (P<0.01) in the third year (2017/18) compared to other seasons. The combined other-grass group was >80% sweet vernal (*Anthoxanthum odoratum* L.); however, this species was affected little by lime rate and so the abundance of different other-grass species was driving the lime rate effect.

The abundance of subterranean clover (the dominant legume) was greater (16-22% vs. 11%, P<0.05), and that of chewings fescue less (1-6% vs. 14%, P<0.01), at all lime application rates compared to the control. Other grass (e.g., *Poa annua*, *Agrostis capillaris*) and legume (e.g., *Trifolium dubium*) species contributed less than 5% to cover and were not affected by treatment or year.

There was some indication that the drought year (early 2018) altered botanical composition. For example, the effects of lime rate on ryegrass, weeds, white clover, subterranean clover and other grasses that had clearly emerged by the third year, disappeared in the fourth year.

The botanical dissections showed that sweet vernal on average comprised two-thirds of the total DM content of the control plots, but over the summer this was superseded by dry stalk and dead tissue. In the first year the quantity of ryegrass increased with increasing rates of lime, but this was not apparent in the second year, as also observed in the point analysis survey of that year. Subterranean clover content in late spring increased with lime application rate in the second and fourth years and chewings fescue content declined with increasing rates of lime in all years. At the end of February in the fourth year during the heat of the drought period, green leaf tissue in the 10 t/ha treatment comprised nearly 50% of the total DM, whereas in all of the other treatments it comprised less than 25% of the total. This effect could be seen visually too, with more green leaf tissue in plots of the 10 t/ha treatment, which is evidence of better plant survivability and vigour due to the known relationship between moisture stress conditions and Al levels (Morton 2020).

Table 1 Effects of five lime rate treatments on soil exchangeable aluminium (Al mg/kg), soil Quicktest calcium (Ca) and soil pH, for 75-150 mm soil depth 4 years after application.

Soil property	Control	1.25 t/ha	2.5 t/ha	5 t/ha	10 t/ha
Exchangeable Al	9.1	9.0	5.6	4.0	3.6
Quicktest Ca	2	2	2	3	4
pH	5.2	5.2	5.4	5.5	5.5

Pasture herbage accumulation

Pasture productivity increased significantly with increasing rates of lime (Figure 3), but there was no significant interaction with year. In the first year, the lower rates of lime grew 20-30% more DM than the

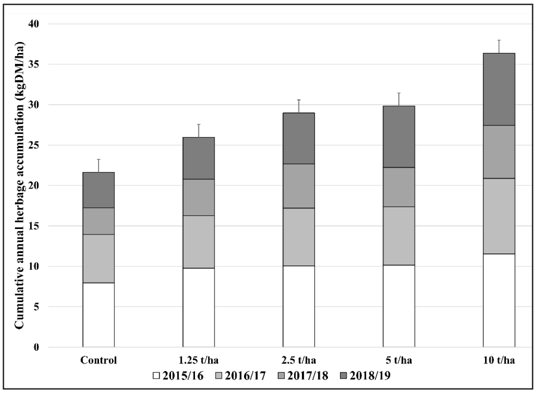

Figure 3 Annual herbage accumulation across five lime rate treatments over four growing seasons. Bars represent pooled LSD.

control plots and the 10 t/ha treatment grew 45% more DM. These differences were accentuated as the trial progressed, so by the fourth year, plots of the 1.25 t/ha treatment had cumulatively grown 20% more than those of the control treatment, the 2.5 t/ha treatment grew 34% more, the 5 t/ha treatment almost 38% more and plots of the 10 t/ha treatment had grown 68% more than the production of the control plots.

Pasture quality

There were no significant differences in pasture grazing heights and no consistent trends in Brix levels between the lime treatments.

During the first autumn (2016), the crude protein, ME and OMD levels increased with rate of lime applied; ADF and NDF levels decreased. Thereafter there were no observed differences in feed quality between treatments over winter, spring and summer of the following years, which may be the result of the irregularity of sending samples to the laboratory for analysis, and when they were, these were only ever from the mature pasture cuts harvested from under the cages. There were higher Ca levels with increasing rates of lime, but no consistent differences between treatments for any of the other elements tested.

This trial was unable to clarify the role of lime in improving the palatability of pasture. The observation from local farmers is not only with sheep, which tend to be more selective eaters, but also with cattle. Two farmers in the group who farm bulls, observed them eating limed pastures more than un-limed pastures. One farmer had also observed bulls preferentially grazing the end of a paddock which had received an overflow of lime drift from the neighbouring paddock. Improved pasture species composition towards increased ryegrass and clover content as demonstrated in this trial could be a possibility, but grazing height residuals in this trial did not detect this. Sheep graze clovers preferentially in a sward compared to grasses (Ridout & Robson 1991), and since this trial site lacked perennial clovers over the critical summer and autumn, it may be one reason for not finding lower grazing residuals on limed plots. Although subterranean clover was more prevalent on the limed plots, it mainly grows over the winter and spring when pastures are grazed to lower heights (Dodd et al. 1995), so lower grazing residuals at that time of year would be less observable. It is also a more prostrate-growing legume, so is normally shorter than the grass species in the sward canopy. Another possible cause for giving limed paddocks the appearance of increased consumption by animals is that with a higher legume content and higher levels of N recycling, lower fertility grasses would grow more leaf tissue before going to seed. Sweet vernal seed head is notorious for being ungrazed by livestock, but with more leaf material on limed pastures, these stems could more likely be eaten and not selected against by animals.

The reasons for such dramatic and sustained production responses to lime are likely to be caused by mitigating the effects of Al toxicity on higher-performing pasture species, particularly perennial ryegrass in this trial. The productive potential of the resident, low-fertility grasses sweet vernal and chewings fescue, and prostrate dicot weeds, will be significantly less than ryegrass and clovers (Grant et al. 1972), so increased ryegrass prevalence will account for some of the increase in DM yields.

The site-specific environmental challenges of mild winters and drier summers compared to other parts of Waikato would mean that increased rooting depth of ryegrass will give greater drought tolerance and survivability of these improved species, hastening pasture recovery post-drought. With deeper and stronger root growth, moisture retention over summer is also likely to improve as observed by Jiayou et al. (1993) on the north-facing Massey University hill farm ‘Tuapaka’. This too can be a factor for some of the production differences between lime treatments.

What remains unanswered is the significant overall DM production increase of the 10 t/ha treatment compared to the 5 t/ha and the lower rates of lime. Such large increases would not normally be expected from raising soil pH levels from 5.7 to 6.2 or seeing decreases in exchangeable Al from 3.4 to 1.1 mg/kg in the top 7.5 cm soil profile. Edmeades et al. (1983) found the critical $CaCl_2$-extractable Al levels for white clover to be 3-5 mg/kg, with the other two dominant species at this site being of similar sensitivity (ryegrass and subterranean clover, Wheeler et al. 1992). So, the differences in production between these two treatments is unlikely to be solely due to Al toxicity. Morton & Moir (2018) suggest that once soil pH exceeds 5.5, Al toxicity issues should normally be alleviated, though this will vary with soil type (Whitley et al. 2016) with some soils showing toxic Al levels at pH figures above 5.5.

Residual organic N mineralisation may not account for the response to the 10 t/ha treatments either, because this effect would have expected to have been greatest in the first 2 years as the microbial population would explode with the rapid initial rise in soil pH. A trial on a dryland soil in Hawke's Bay had shown responses to lime of 10-20% in the first 2 years (Edmeades et al. 1990) which were attributed to a stimulation of the grass component of the sward by enhancing the rate of net mineralisation of organic N, but in the following years this effect waned and was not significant. The owner of Piquet Hill Farm observed this organic N mineralisation flush within 3 weeks of starting the trial, where the plots receiving higher rates of lime were visually growing considerably more in the cages than those plots receiving less or no application of lime.

Economics of lime

When considered over a 4-year period, assuming a lime cost of $30/t, cartage cost of $25/t and application cost of $65/t by plane, the costs per kg of DM over the control in this trial were:
1.25 t/ha – 3.6c/kg DM
2.5 t/ha – 3.8c/kg DM
5 t/ha – 7.3c/kg DM
10 t/ha – 7.9c/kg DM
If applied by truck and the application cost decreases to $20/t, the costs per kg of DM would be:
1.25 t/ha – 2.2c/kg DM
2.5 t/ha – 2.4c/kg DM
5 t/ha – 4.6c/kg DM
10 t/ha – 4.9c/kg DM

Conclusions/Practical implications/Relevance

The key message is that if pH and Ca levels are low and this is compounded with Al toxicity and drought susceptibility, the economics of applying lime whether by plane or truck can still be highly profitable. These results align with some local farmer observations in the Te Akau/Waingaro region where farmers have applied lime and anecdotally noticed significant changes in pasture and stock performance. With improved pasture performance and greater pasture recovery post-drought, liming provides opportunities to fatten lambs and grow cattle faster with higher quality pasture species during autumn in particular. It should be stressed that the results from this trial are specific to this site with its unique climate, soil type, stocking regime and pasture composition and cannot be extrapolated to other sites with similar background soil fertility levels.

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