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Effects of lime on pasture production on soils in the North Island of New Zealand 5. Description of a lime recommendation scheme

D. C. EDMEADES
Ruakura Soil and Plant Research Station, MAF
Private Bag, Hamilton, New Zealand

R. M. PRINGLE
G. P. MANSELL
Agricultural Research Division, MAF
P.O. Box 1654, Palmerston North, New Zealand

P. W. SHANNON
Agricultural Research Division, MAF
P.O. Box 943, Whangarei, New Zealand

J. RITCHIE
Advisory Services Division, MAF
Private Bag, Te Kuiti, New Zealand

K. M. STEWART
Advisory Services Division, MAF
P.O. Box 1654, Palmerston North, New Zealand

Abstract A lime recommendation scheme for established pastures on mineral soils is described. The scheme is based on a simple model, using soil pH, to estimate the size of pasture responses to lime at 3 rates of application (1.25, 2.5, and 5.0 t/ha). The estimated pasture production responses to lime are converted to increases in animal production, from which the potential economic benefits of liming are calculated. The limitations and accuracy of the model are discussed. The importance of liming relative to fertiliser nutrient inputs is also discussed and, in particular, it is concluded that lime and fertiliser inputs should be assessed independently. Recommendations for the use of lime on organic soils are also presented.

Keywords models; lime; soil amendments; fertilisers; soil pH; pasture production; mineral soils; organic soils

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INTRODUCTION

The first comprehensive set of lime recommendations for New Zealand soils was published by During (1961, 1962). This information was updated in subsequent publications (During 1972; Lynch & During 1978).

In general, lime was recommended to achieve maximum production on established pastures on most intensively farmed New Zealand soils. Exceptions were the so-called volcanic soils (the yellow-brown loams and yellow-brown pumice soils) on which variable results from liming had been obtained. Liming was not regarded as essential for establishing pastures except on very acid soils (pH < 5.0), such as peats or the strongly weathered soils of Northland and the West Coast. The general philosophy as first propounded by Connell (1931) and repeated by others (During 1972; Edmeades et al. 1981, 1982; O'Connor & Mansell 1982) was that priority should be given to correcting nutrient deficiencies as "lime alone seldom proves a worth-while proposition". Where lime was required, a pH 5.5–6.2 for mineral soils (depending on soil type) and 5.0 for peats, was recommended. To maintain optimum pH, it was recommended to apply 2.5 t limestone/ha every 3–6 years, depending on rainfall and soil type.

The situation on hill country soils was more complex. Although many of these soils were known to be responsive to liming and/or molybdenum, the use of lime on hill country soils was not considered economic because of the cost of aerial application (During 1961 p. 437, 1962 p. 73). The recent work by O'Connor and co-workers (O'Connor et al. 1981) has since shown that, on many of the sedimentary hill country soils, low rates of lime (1.25 t/ha) can be economic.

The approach used by During (1961; 1962, 1972) and Lynch & During (1978) was based solely on achieving and maintaining a target pH. There was no attempt to predict or quantify responses to lime either in terms of pasture production or economic returns. The objective of this paper is to describe a lime recommendation scheme for established pastures on soils in the North Island, New Zealand.

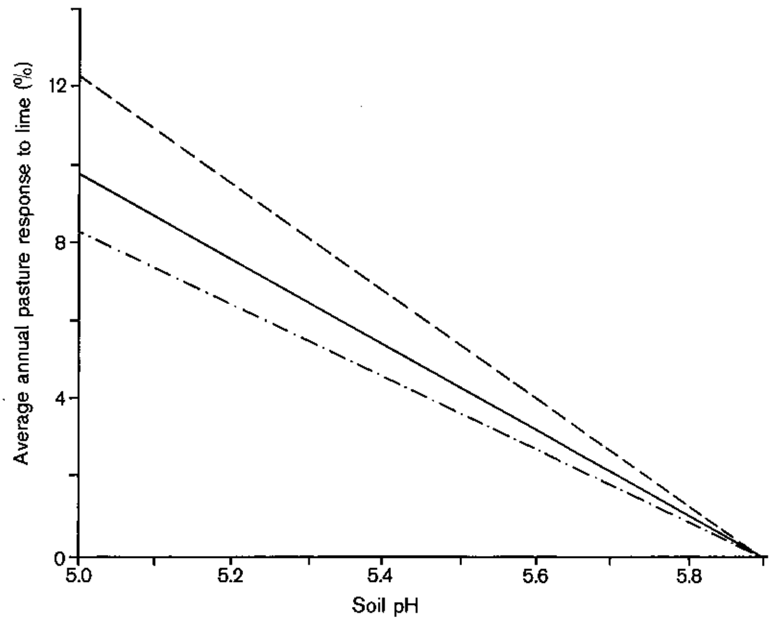

Fig. 1 Relationships between soil pH and average annual pasture response (%) to lime at 3 rates of application:
—·—·— 1.25 t/ha;
——— 2.5 t/ha;
– – – – 5 t/ha.

This is accomplished by:

(1) developing a model, based on the results obtained in Papers 1–4 of this series (Edmeades et al. 1984b, 1984c; Shannon et al. 1984; Mansell et al. 1984), to predict lime responses from soil pH;
(2) examination of the duration of lime responses;
(3) considering the effects of liming on the availability of fertiliser nutrients and the importance of liming relative to fertiliser applications;
(4) discussing the effects of lime on animal production and health;
(5) using selected examples to examine the economic outcome of liming, based on predicted lime responses from the model;
(6) reviewing the use of lime on organic soils.

In this way, a comprehensive scheme, which can be used for making "on-farm" lime recommendations, is developed.

MATERIALS AND METHODS

A description of the data base on which the model for predicting lime responses is based is given in Paper 1 (Edmeades et al. 1984b), together with a description of the methods used for the measurement of soil pH, phosphorus (P) status, soil texture, buffer capacity, and pasture production. The quantitative relationships between pasture response to lime and soil pH are derived in Paper 4 (Edmeades et al. 1984c). A discussion of the seasonality of lime responses and its implications is given in Paper 2 (Shannon et al. 1984) and lime × P interactions are examined in Paper 3 (Mansell et al. 1984).

Some additional information, either not used or not discussed in Papers 1–4, is drawn upon in this paper. Soil pH data used to estimate lime maintenance rates are taken from long-term field trials (Research Division, MAF, unpublished data). Similarly, information on the effects of incorporating lime into peat soils is taken from unpublished trials (Research Division, MAF).

RESULTS AND DISCUSSION

Model for predicting pasture responses to lime

In Paper 4 of this series (Edmeades et al. 1984c) it was shown that pasture responses to lime are related to soil pH and that all mineral soils in the North Island, at a given pH, gave similar pasture responses to liming. These results can be summarised by 3 generalised relationships between soil pH and pasture responses to lime, at 3 application rates; 1.25, 2.5, and 5.0 t/ha (Fig. 1). All 3 soil pH–lime response relationships intercept the x-axis at 5.9. This is a simplification of the original results which indicated intercepts of between 5.7 and 6.1, for different soil groups and rates of lime (Tables 4 and 5, Edmeades et al. 1984c). However, given the errors in determining the intercept, this simplification is reasonable. The soil pH above which there is no

Table 1 Comparison of regression equations of percent response to lime (y) and soil pH (x) derived from North Island and South Island trial results.

Rate of liming (t/ha)	Island	Equation	r	No. of trials	Intercept x-axis
1.25	North[1]	$y = 54-9.1x$	−0.45	50	5.90
	South[2]	$y = 46-7.8x$	−0.50	15	5.92
	(Pooled)[3]	$y = 51-8.6x$	−0.50	65	5.93
2.5	North	$y = 61-10.4x$	−0.38	95	5.91
	South	Only 2 data points			
	(Pooled)	$y = 64-10.8x$	−0.38	97	5.93
5.0	North	$y = 77-13.1x$	−0.56	61	5.93
	South	$y = 79-13.2x$	−0.75	17	5.91
	(Pooled)	$y = 79-13.4x$	−0.62	78	5.90

[1] Edmeades et al. (1984c);
[2] McIntosh (1980), using trials from developed pastures only;
[3] These results differ slightly from those in Fig. 1 because the regression lines were not fitted through soil pH 5.9.

Table 2 Comparison of lime responses predicted from the model and measured in a set of ongoing field trials not included in the data base.

Rate of liming (t/ha)	n[1]	Range in soil pH from trial sites	Lime response (%)	
			Predicted	Measured
1.25	2	5.4—5.5	4.2(3.5—5.0)[2]	6.5(2.5—10.5)
2.5	6	5.1—5.8	5.6(1.0—8.5)	5.7(−1.9—13.0)
5.0	7	5.2—5.8	6.9(1.0—9.5)	5.0(−0.2—15.5)

[1] n = Number of trials;
[2] Mean and range (in brackets).

response to lime, is given by the intercept on the x-axis in Fig. 1. This can loosely be defined as the "optimum" pH and according to the present data is 5.9. This optimum pH assumes an adequate supply of all major and minor nutrients, especially molybdenum (Mo).

How good is the model?

The model predicts the average pasture response to lime at any given pH. However, there is some variation in the pH/lime response relationships, as indicated by the correlation coefficients (Table 1). Despite this variation, similar relationships were found for different soil groups and a selected set of 25 trials under the same management (Edmeades et al. 1984c), and for an independent set of trial results from the South Island (Table 1). These results together suggest that the relationship between the average response to lime and pH can be clearly defined.

Some indication of the variation in predicting mean response is given by the results in Table 2, which have been obtained from a set of ongoing field trials, which had been in progress for at least 3 years at the time of writing and are not included in the data base. These results illustrate the 2 points made earlier. Firstly, there is good agreement between the average measured responses and those predicted by the model. Also, the range in the measured lime responses is greater than that predicted by the model, indicating that factors, other than pH, are contributing to the size of the measured lime responses. Possible sources of this variation, as discussed in Paper 4 (Edmeades et al. 1984c), include year-to-year and seasonal variability in lime responses, the effects of pasture composition and pasture grazing pressure on lime responsiveness, and temporal variations in pH.

A further 8 trials have recently been initiated by the Ministry of Agriculture and Fisheries. Results from these trials, together with those from the other ongoing trials, will be used to further test the model, when at least 3 years' production data is available.

Table 3 Comparison of measured and predicted responses to lime on 4 grazing trials.

Trial	pH	Stock class	Stocking rate (stock units/ha)	Pasture response(%)	
				Measured	Predicted
Hamilton	5.6	sheep	variable	6	5
Stratford	5.6	dairy	29	6	5
Masterton	5.5	sheep	15	7	6[1]
			22	19	6
Te Kuiti	5.4	sheep	14	(5–10)[2]	4

[1] Model does not account for effect of stocking rate.
[2] Animal responses (%).

In 2 of these trials large lime × P interactions have occurred. Reasons for these interactions are being investigated with a view to improving the accuracy and sophistication of the model.

The "optimum" soil pH predicted by the model is consistently close to 5.9 (Table 1). This is in agreement with recommendations for pastures in Great Britain (Ministry of Agriculture, Fisheries & Food 1981) and the United States (Pearson & Hoveland 1974). In our opinion, this is further evidence that the model is useful for making practical lime recommendations.

The model is largely based on results obtained from mowing trials. Evidence which shows that the relative pasture responses to lime are similar whether obtained from mowing or grazing trials is presented in Paper 1 (Edmeades et al. 1984b). Furthermore, the results in Table 3 show that there is general agreement between measured pasture responses to lime under grazing and those predicted from the model.

The size of treatment responses in grazing trials can be affected by stocking rates, and the importance of this has been discussed elsewhere (e.g., Bircham & Crouchley 1976; Edmeades et al. 1982; O'Connor & Mansell 1982). This stocking rate effect is reflected in the data from the Masterton trial (Table 3), where the predicted response was the same as that measured at the lower stocking rate, but was less than that measured at the higher rate. However, although there is insufficient data for the effect of stocking rate on pasture lime responses to be quantified, the above evidence shows that as stocking rate increases, the size of the lime response will also increase, and hence improve the profitability of liming (see Section on Evaluation of the economics of liming on mineral soils).

A possible limitation of the data base, on which this model is based, is the relatively few trials on both yellow-brown pumice soils and central yellow-brown earths (10 and 3, respectively) (Edmeades et al. 1984b, Table 1). These soil groups represent a large proportion of the North Island (Edmeades et al. 1984b, Table 1). However, this is probably not a serious limitation in the instance of the central yellow-brown earths which are expected to respond similarly to other closely related soil groups (Edmeades et al. 1984c). For the yellow-brown pumice soils it is not known how serious this limitation is. There are only 10 trials from this soil group on the data base and the responses to lime were not related to soil pH (Edmeades et al. 1984c). In the absence of sufficient information, it is assumed that these soils respond similarly to other mineral soils. Further trials in progress will assist in validating this assumption.

The model uses soil pH as the sole predictor of lime responses. This is based on the results discussed in Paper 4 (Edmeades et al. 1984c) which showed that other factors, such as P status, soil buffer capacity, and soil texture, did not significantly improve the prediction of lime response. Nevertheless, we believe that this simple model represents a significant improvement in terms of predicting and quantifying the effects of lime.

Interpreting soil pH

Soil pH can vary both in time and space (Mountier & During 1977) and this may result in errors in predicted lime responses. A recent study (Edmeades & Wheeler unpublished data) has shown that while this variation can be up to ± 0.2, it rarely exceeds 0.1 pH units. This variation can be reduced by resampling soils in the same season of each year (Cornforth & Sinclair 1982).

Interpreting annual pasture responses

The model relates soil pH to *annual* pasture dry matter responses to lime. As discussed in Paper 2 (Shannon et al. 1984), liming generally has its largest beneficial effects on pasture production in summer and/or autumn. This has important practical implications in that the responses occur at times when feed supplies are critical. Although the effect of seasonality was observed in all of the trials described in Paper 2 (Shannon et al. 1984), it is still not possible to quantify this beneficial effect in any given farm situation.

Duration of lime responses

Trial data in the North Island on the effects of lime on soil pH over a long period of time are scarce, and the available information is variable. Accordingly, it is difficult to be precise about the duration of lime responses. In terms of making recommendations on the need for reliming, information on the duration of lime responses is not important because soil pH can be readily monitored as required. However, assessment of the economic benefits of liming (discussed later) requires information on the duration of lime responses.

The results in Fig. 2 show some examples of the effect of a single application of lime on pH over time for various soils. From field trial data such as these, it is possible to calculate the change in soil pH per unit time following liming. Using this information, together with the soil buffer capacity (change in soil pH per unit of lime applied), the duration of the effect of lime on soil pH can be estimated.

This has been done for a set of 5 trials on central yellow-brown earths and yellow-grey earths. These calculations show that the mean duration of a single application of 1.25, 2.5, or 5.0 t lime/ha on soil pH is 7, 8, or 9 years respectively. Similar calculations based on data from yellow-brown loams, yellow-brown pumice soils, and northern yellow-brown earths gave variable results, but suggested that the effect of a single application of lime on soil pH lasts at least as long as on central yellow-brown earths and yellow-grey earths.

These results are consistent with those obtained by Doak (1941) who estimated a rate of loss of lime of 350–400 kg/ha per year. This is equivalent to an effect on soil pH lasting about 7 years after a single application of 2.5 t lime/ha. Results from Te Kuiti, on a central yellow-brown earth, show that the effects on animal production of a single application of 1.25 t lime/ha were still evident after 6 years (M. B. O'Connor pers. comm.).

Using the above data, together with results from the South Island, the duration of the pH effect of liming was correlated with rainfall (A. G. Sinclair pers. comm.). Sinclair calculated that the number of years' duration of the pH effect was equal to:

$7 - (0.0012 \times \text{annual rainfall (mm)})$
for 1.25 t lime/ha;

$9 - (0.0012 \times \text{annual rainfall (mm)})$
for 2.5 t lime/ha; and

$11 - (0.0012 \times \text{annual rainfall (mm)})$
for 5.0 t lime/ha.

Trial results show that the effects of lime on pasture and animal production may (Bircham & Crouchley 1976) or may not (O'Connor et al. 1981; Thomson 1981) occur in the first year following lime application.

The information above on the duration of the effect of lime on soil pH and on pasture and animal responses to lime has important implications for calculating the economic benefits of liming. It is prudent to assume no animal responses and, therefore, no economic benefits in the first year after liming. Therefore, economic benefits will accrue for 1 year less than the duration effect on pH as estimated by Sinclair.

Lime and fertilisers

Priorities

The importance of liming relative to the correction of nutrient deficiencies depends not only on soil fertility principles but also on the individual objectives and economic situation. Although these aspects have been discussed elsewhere (Connell 1931; Blackmore et al. 1969; Edmeades et al. 1982; O'Connor & Mansell 1982; Edmeades et al. 1984a), the following guidelines are useful.

(a) On very acid soils ($pH \leqslant 5.5$), such as peats or highly weathered soils — both lime and fertilisers are essential for pasture establishment and maintenance.

(b) On soils where the pH is below optimum ($5.0 < pH \leqslant 5.8$) and the objective is to achieve maximum production regardless of cost — apply both lime and fertilisers.

(c) As for (b), but where available finances are limited — the correction of nutrient deficiencies should be given priority because responses to liming are generally much smaller (0–10%) than responses to the correction of nutrient deficiencies (often above 100%) (Blackmore et al. 1969; Edmeades et al. 1982, 1984a).

Effects of lime on fertiliser nutrients

A popular opinion about liming is that it unlocks soil P making it more available for plant growth. This effect is often referred to as the P-sparing effect of lime. However, one of the conclusions reached in Paper 3 (Mansell et al. 1984) of this series, was that the P-sparing effect of lime should not be an important consideration when determining lime and fertiliser policies. This conclusion was based on the finding that, although negative lime × P interactions are common, sizable P-sparing effects because of lime are rare and very difficult to predict. These results endorse Connell's (1931) claim, "that lime is not a substitute for fertiliser" — in this instance, P. It would be unwise, therefore, to recommend to farmers to reduce P inputs as a result of liming.

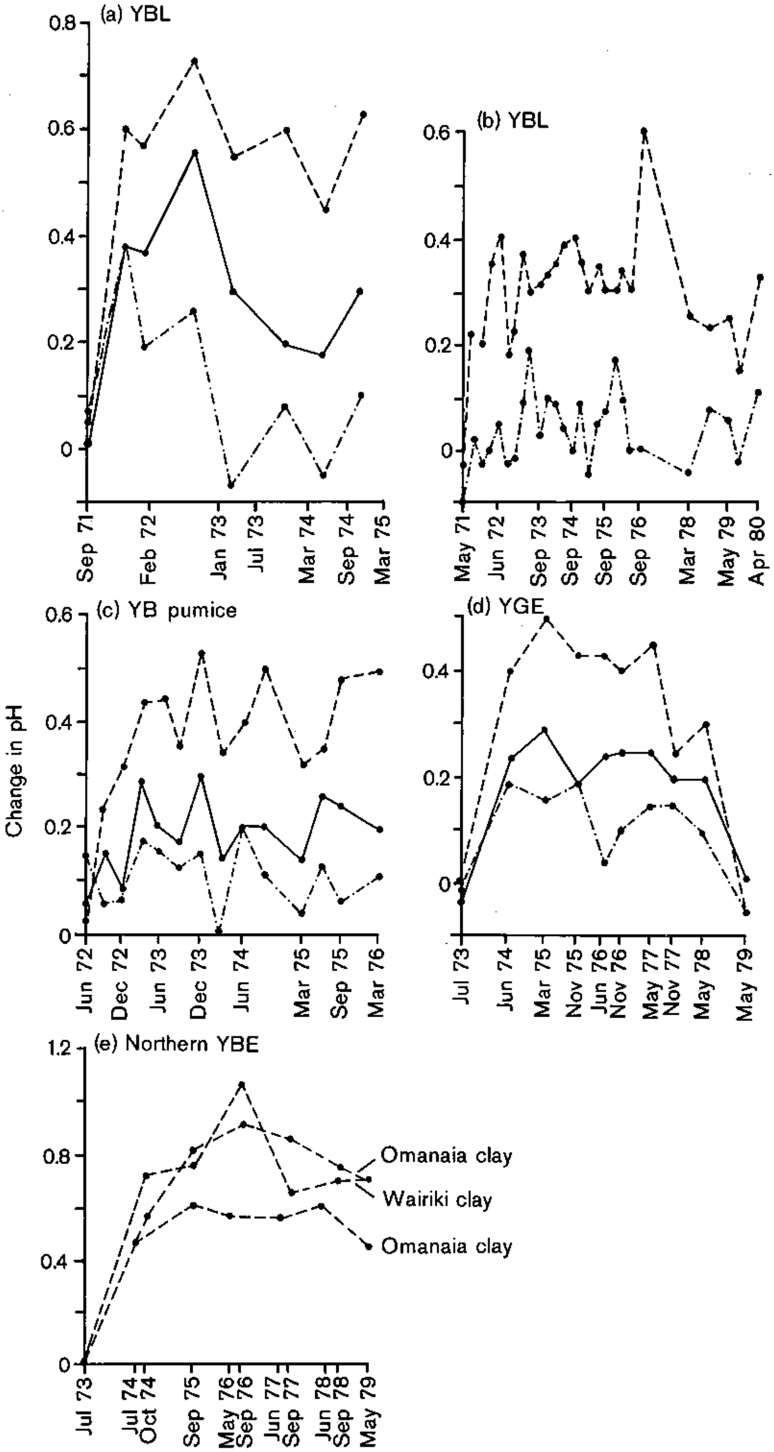

Fig. 2 Examples of the effects of a single application of lime at various rates on the change in soil pH over time for: (a) yellow-brown loam; (b) yellow-brown loam; (c) yellow-brown pumice soil; (d) yellow-grey earth; (e) 3 northern yellow-brown earths. (Lime: —·—·— 1.25 t/ha; ——— 2.5 t/ha; – – – – 5 t/ha.)

The interaction between lime and Mo is well understood and documented in New Zealand (Davies 1951; Cullen 1955; Askew 1958; During 1961, 1962, 1972). Because of this interaction and the negative effect of Mo on copper (Cu) availability, as discussed in the section below, caution is necessary if both lime and Mo are applied together.

There is some evidence that liming may increase soil exchangeable-potassium (K) and -sodium (Na), because of an increase in soil cation exchange capacity (Edmeades 1982; Edmeades et al. 1983). Theoretically this may result in a reduced input of these nutrients on some soils but further research is necessary to quantify this effect.

Most New Zealand limestones contain a small proportion of magnesium (Mg), between 0.1 and 0.5% (M. Brown pers. comm.) but, despite this, liming generally decreases soil exchangeable-Mg (Askew et al. 1958; Edmeades 1982). These results suggest that liming may increase the losses of Mg and hence increase the need for fertiliser Mg on some soils. However, this effect is generally small and is probably only important on soils where the Mg status is low (MAF Quick Test Mg < 10).

Animal production and health

This study assumes that the effects of liming on animal production can be predicted from its effects on pasture growth. The justification for this assumption is that the results from several animal grazing trials (Edmeades et al. 1984b) show a general relationship between pasture and animal production responses to liming. In addition, the results from a pasture allowance study (O'Connor et al. 1984) show that the liveweight gains of lambs are similar for limed and unlimed pasture, suggesting that liming does not improve pasture "feeding value". Also, farmers have observed that animals prefer limed pasture. This observation is understandable if liming improves the proportion of desirable species in the sward. However, in a 2-year grazing trial in Taranaki on a good quality ryegrass – white clover pasture on which liming had no effect on pasture composition, there was no evidence of a grazing preference for limed pasture (Rys & Edmeades 1984). The conclusion from all of these trials is that, if liming has a beneficial effect on animal production and health, then it is primarily the result of an increase in the availability of pasture.

There is another popular view that liming can be beneficial to animal health by changing the mineral composition of pastures. However, there is no experimental evidence to support this. The major and most consistent effects of liming on pasture mineral composition are to decrease Mg and manganese (Mn), and increase calcium (Ca) and Mo (During & Rolt 1967; McNaught et al. 1968, 1973a, 1973b; Lambert & Grant 1980; Edmeades et al. 1983; Thomson 1981). Generally, liming has little effect on concentrations of the macronutrients P, nitrogen (N), sulphur (S), K, Na, or of the micronutrients Cu, boron (B), and cobalt (Co), over the pH range of 5.0–6.0 usually encountered in agricultural practice (Edmeades et al. 1983). The decrease in herbage Mg and increase in Ca have been implicated as a factor in the increased incidence of clinical hypomagnesaemia in lactating dairy cows (Thomson 1981). These effects of liming appear to be greatest in the late winter – spring (Edmeades et al. 1983).

Cunningham (1954) warned that overliming could induce Cu deficiency in animals. As stated earlier, liming has little effect on plant Cu but increases Mo, resulting in a decrease in the Cu:Mo ratio. The critical ratio of Cu:Mo has not been clearly defined for animals grazing pasture, but Gupta & Lipset (1981) suggest that ratios of < 4 can be expected to result in molybdenosis.

One of the greatest effects of lime on plant chemical composition is to decrease Mn. However, it is unlikely that liming, by alleviating Mn toxicity, will result in any change in animal production. Grace (1973) reported that Mn concentrations higher than 400 mg/kg are required before growth rates of sheep are depressed and, as shown elsewhere (Smith & Edmeades 1983), pasture concentrations of Mn exceeding this are rare in New Zealand.

Organic soils

Organic soils are classified as those with more than 20% organic carbon in the topsoil (New Zealand Soil Bureau 1970). Peats are separated from peaty loams on the basis that they have more than 40% organic carbon.

Organic soils differ from mineral soils in their requirements for lime. They do not contain the "minerals" present in mineral soils and therefore the pH required for optimum production is less. Below the optimum pH, pasture responses to liming are large. Therefore, liming is essential and probably always economic. Another consideration is that the subsoil pH of most peats is very low but surface-applied lime does not move down into the subsoil. Therefore, physical incorporation of lime into the subsoil is important.

The results from trials on peat soils in the Waikato Basin (Edmeades et al. 1984c, Fig. 8) show that above a soil pH of 5.0 (0–75 mm depth), pasture responses to lime are relatively small. At lower soil pH, large responses to lime can be obtained. The number of trials is small and therefore it is not possible to establish precisely the relationship between soil pH and pasture response to lime on these soils. However, because the responses to lime are large, lime is essential and probably always economic for pasture development and maintenance, if the pH is < 5.0 (0–75 mm depth).

The importance of incorporating lime into the subsoil is illustrated by the results in Table 4, on a newly sown virgin peat. An important consequence of deep liming is that pastures are better able to tolerate moisture stress in the summer (van der Elst 1962). According to van der Elst, this occurs because "during the summer, plant roots have to obtain moisture from deeper soil layers in order to survive". This is possible only when the pH of the subsoil is high enough to permit root penetration. The results in Fig. 3 suggest that a subsoil pH of at least 4.5 (75–150 mm depth) is necessary to achieve good production. Thus, for pasture establishment and maintenance a minimum pH of 5.0 (0–75 mm depth) and 4.5 (75–150 mm depth) is recommended. In the process of renewing old pastures it is beneficial to apply more lime to the acid peat brought to the surface during cultivation.

The amount of lime necessary to achieve the minimum target pH values can be calculated from the data summarised in Table 5. Examples showing how to use this information are given elsewhere (Edmeades et al. 1984d).

The results above have been derived from trials on peats and peaty loams in the Waikato Basin. They may not be applicable to other peat formations.

The target pH values suggested are minimum only. There is no experimental evidence to show the effects of higher pH on pasture production on peats. Similarly, there is no information on the long-term maintenance of pH in peat soils. It is suggested that soil sampling to 2 depths be undertaken at regular intervals (every 2–3 years) to determine when lime is next required.

Table 4 The effect of rates of lime applied to the surface and incorporated into subsoil on pasture production (kg dry matter/ha) on a Moanatuatua virgin peat.

	Rate of lime (t/ha)					
	0	2.5	5.0	10	15	20
Surface-applied	2500	3500	4300	3700	3800	3000
50% incorporated/ 50% surface-applied		4700	6300	6400	6900	6800

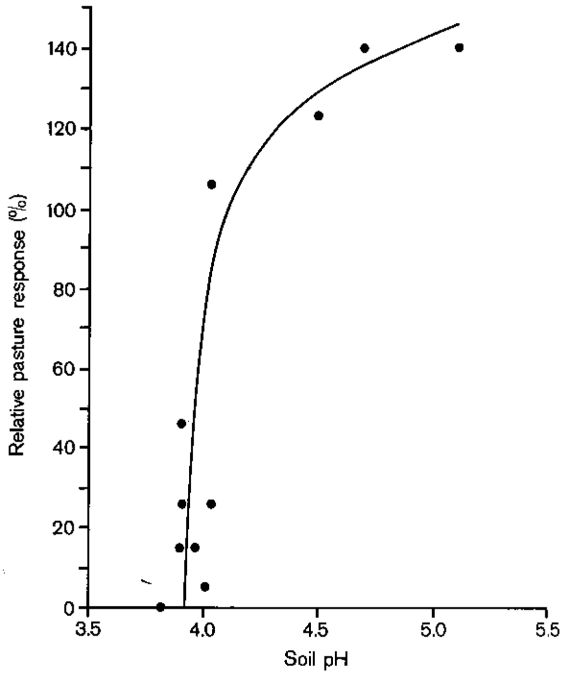

Fig. 3 Relationship between relative pasture response (%) and soil pH (75–150 mm depth) on a virgin peat.

Evaluation of the economics of liming on mineral soils

This section describes an approach which can be used to determine the most profitable rate of lime to apply to mineral soils. There are several approaches which could be used to examine the economics of liming. For example, it is necessary to decide whether the extra feed produced by liming will be utilised by the existing stock or whether stock numbers will be increased. In the following examples, it is assumed that stocking rate is increased while per head production is maintained. This has been done to simplify the calculations and because it is considered to be the most efficient means of utilising additional pasture. In a simulation model study of the utilisation of extra feed on a set-stocked sheep farm, Barlow (1985) found that the increase in gross margin per ha when stock numbers were unchanged was, depending on initial stocking rate, between 45 and 100% of the extra gross margin realised by increasing stocking rate. In his example, near parity between the 2 systems was achieved only at high stocking rates.

The economic analysis used in this paper involves the calculation of the net present value per ha for each rate (1.25, 2.5, and 5.0 t/ha) of lime. The costs of liming include those of the purchase, cartage, and spreading of lime, and of the extra stock. The cost of extra stock is calculated from the percentage pasture response (R) to a rate of lime, the initial stocking rate (S), and the per head cost of extra

Table 5 Summary of results showing the effect of method of application and degree of development on the amount of lime required to raise the soil pH of organic soils by 1 pH unit.

		Lime required (t/ha)	
Method of application	Soil depth (mm)	Virgin peat	Previously developed peats and peaty loams
Surface-applied	0– 75	no data	9
	75–150	no data	no effect
50% incorporated/	0– 75	7	16
50% surface applied	75–150	17	34

Table 6 Example of inputs required for economic evaluation of liming on a typical Waikato dairy farm.

1.	Initial soil pH	5.6
2.	Average annual rainfall (mm)	1500
3.	Lime cost ($/t ex works)	13
4.	Freight to farm minus transport subsidy ($/t)	10.7
5.	Application costs ($/t) at each liming rate	7.65 (1.25 t/ha) 5.95 (2.5 t/ha) 4.00 (5 t/ha)
6.	Present stocking rate (dairy cow equivalent/ha)	2.5
7.	Gross margin ($/dairy cow equivalent)	450
8.	Cost of extra stock ($/cow)	500
9.	Salvage value ($/cow)	500
10.	Discount rate (%)	10

Table 7 Summary of economic evaluation of liming on a typical Waikato dairy farm at 3 rates of lime.

Rate of liming (t/ha)	Response[1] to lime (%)	Extra stock (stock unit/ha)	Lime costs ($/ha)	Cost of extra stock[2] ($/ha)	Annual extra gross margin ($/stock unit)	Duration[3] of benefit (years)	Net present value ($/ha)
1.25	2.86	0.07	39.20	35.75	32.18	4	55
2.50	3.22	0.08	74.10	40.25	36.22	6	70
5.00	4.26	0.11	138.50	53.25	47.92	8	94

[1] These are derived from Figure 1 using the initial soil pH.
[2] = Salvage value, in this instance.
[3] See section on Duration of lime responses for calculation of duration of benefit.

stock (C): i.e., cost of extra stock = RSC/100. The cost of lime is borne in the year of application and (as was explained in the section on Duration of lime responses) the cost of extra stock in the year following lime application.

If G is the gross margin per stock unit (or dairy cow equivalent (DCE)), then the annual increase in income to some rate of liming is RSG/100. This benefit will accrue annually but for one year less than the duration of the pH effect of liming, as discussed earlier. Benefits and costs occurring in years other than the year of lime application, are discounted to their present value.

Example 1

An example of the inputs required to undertake the calculations of net present values for a typical Waikato dairy farm (1983–84 costs and prices) is given in Table 6. Table 7 presents a summary of the calculations. The results in the final column of the latter table show that, for the given inputs, liming is economic at all 3 rates, but the best return is

Table 8 Example of inputs required for economic evaluation of liming on a typical King Country easy hill country sheep farm.

1.	Initial soil pH	5.3
2.	Average annual rainfall (mm)	1000
3.	Lime cost ($/t ex works)	13
4.	Freight to farm minus transport subsidy ($/t)	12
5.	Application costs ($/t) at each liming rate	8 (1.25 t/ha) 6 (2.5 t/ha) 4.5 (5 t/ha)
6.	Present stocking rate (stock unit/ha)	12
7.	Gross margin ($/stock unit)	25
8.	Cost of extra stock ($/stock unit)	30
9.	Salvage value ($/stock unit)	30
10.	Discount rate (%)	10

Table 9 Summary of economic evaluation of liming on a typical King Country easy hill country sheep farm.

Rate of liming (t/ha)	Response[1] to lime (%)	Extra stock (stock unit/ha)	Lime costs ($/ha)	Cost of extra stock[2] ($/ha)	Annual extra gross margin ($/stock unit)	Duration[3] of benefit (years)	Net present value ($/ha)
1.25	5.53	0.66	41.25	19.9	16.6	5	15.9
2.5	6.46	0.78	77.50	23.2	19.4	7	7.6
5.0	8.28	0.99	147.50	29.8	24.8	9	−18.8

[1] These are derived from Figure 1 using the initial soil pH.
[2] = Salvage value, in this instance.
[3] See section on Duration of lime responses for calculation of the duration of benefit.

achieved at the highest rate. The greater benefit accruing from higher rates is a direct consequence of the longer duration of response at those rates. However, it is precisely this area where data are scarce and the equations for the duration of response derived by Sinclair should be considered tentative.

Example 2

The inputs required for calculation of net present values for a typical easy hill country sheep farm in the King Country (1983–84 costs and prices) are given in Table 8. The application costs shown assume that the area receiving lime is suitable for ground spreading. The results in the final column of Table 9 show that, for the example used, liming gave a small economic return at the first 2 rates but that 5 t/ha was not economic.

At 14 stock units/ha and an initial pH of 5.4, the net present value for an application of 1.25 t lime/ha is NZ$15/ha. The trial results of O'Connor et al. (1981) at the same pH and stocking rate suggest a somewhat greater economic benefit at 1.25 t lime/ha. This difference can be attributed to:

(a) the percentage response in pasture production predicted by the model is 4.6, whereas O'Connor

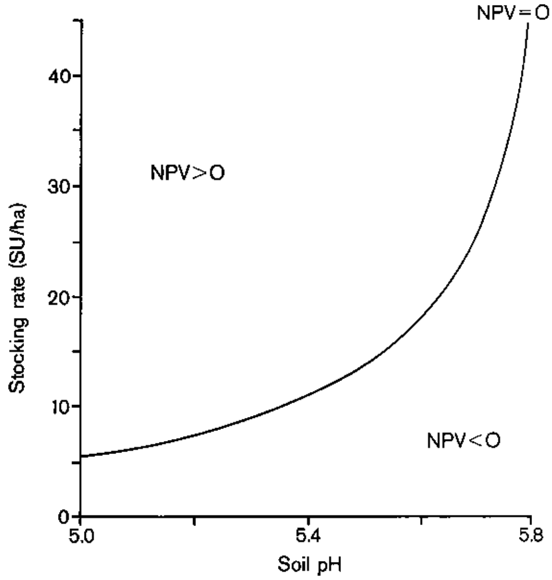

Fig. 4 Combinations of initial soil pH and stocking rate (stock units/ha) on sheep farms, for which the net present value (NPV, $/ha) for a rate of application of lime of 1.25 t/ha, is zero; input data as in Table 8.

et al. (1981) observed responses in animal performance which were slightly higher — this emphasises that the model provides a predicted response and that some variation will occur;
(b) O'Connor et al. (1981) did not discount future sums back to their present values and, therefore, the true costs and benefits were not reflected.

In attempting to determine when liming is likely to be economic on sheep farms, the combinations of stocking rate and initial soil pH for which the net present value is at least zero have been calculated. The break-even combinations are presented in Fig. 4 for the rate 1.25 t/ha. In calculating these values, all other inputs have been held at the levels given in Table 8. Inspection of this figure reveals that on acid soils and at moderate stocking rates, a low rate of lime is worthy of consideration, even on hill country sheep farms.

It is worth emphasising that the objective of these economic analyses is to calculate and compare net present values and hence to provide a recommendation on the most appropriate rate to apply. The net present values are only a good guide to the value of the investment. For this reason, it is important to consider whether the analysis is sensitive to errors in determining soil pH. For example, for the inputs used in example 1 but with a recorded pH of 5.7, problems would arise with a deviation of 0.1 pH units in either direction, because a pH reading of 5.8 would suggest that no lime be applied. However, at lower values of soil pH, the analysis is sensitive in that the order of the net present values does not change with pH.

SUMMARY

The components of a lime recommendation scheme for mineral soils in the North Island, New Zealand, described in this paper make it possible to:
(1) estimate the size of pasture responses to liming at 3 rates of application (1.25, 2.5, and 50. t/ha); (2) convert this pasture response into animal production; and (3) calculate the potential economic benefits of liming. The importance of liming relative to fertiliser nutrient inputs is discussed and, in particular, it is concluded that lime and fertiliser inputs should be assessed independently. Recommendations for the use of lime on organic soils are also presented.

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