



Lime Use on New Zealand Pastoral Farms

Acknowledgments

The work of researchers, past and present, who have conducted field trials under what used to be the Ministry of Agriculture and Forestry (MAF), and later by AgResearch, is gratefully recognised.

The Fertiliser Association of New Zealand acknowledges the expertise of the scientists and technicians involved in this work. Doug Edmeades and Mike O'Connor have prepared the original text and it has been revised and updated by Jeff Morton, Ants Roberts and Greg Sneath.



Published 2019

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ISBN 978-0-9951151-0-1 (Print)

ISBN 978-0-9951151-1-8 (Electronic)

Lime Use on New Zealand Pastoral Farms

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**Fertiliser
Association** 

Shaping profitable and sustainable farming

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Foreword

Agricultural lime plays a vital role in modern farming systems. Over time, most soils become more acidic due to a variety of factors such as leaching, decomposing organic matter, erosion, and plant uptake of essential nutrients. Acidic soils can have significant negative impacts on crop productivity. Plants are able to use nutrients more efficiently with the right pH balance in the soil.

Adding the right amount of lime to soil can neutralise high levels of aluminium and lead to increased biological activity and increased availability of some essential elements.

This booklet summarises our current knowledge about lime. The benefits of lime and best approaches to its use are well established through many decades of research.

The information in this booklet is one of a series, designed to provide farmers and their advisers with reliable nutrient management advice. We trust it will assist you in understanding what will work best for your farm as you develop your nutrient management plan and seek to maximise the productive potential of your soils through efficient use of available nutrients.

Introduction

The pastoral sector is still the engine room of New Zealand's economy and has in the last three decades undergone major rationalisation driven by the ongoing need to be internationally competitive.

Fertiliser and lime inputs are a major cost on most farms and for this reason they are important focal points when considering economic efficiencies.

There has been increasing emphasis on sustainability of soil resources and the greater use of lime to neutralise soil acidification has been part of this.

Nevertheless, there is much improved pasture mainly on hill and high country that does not receive sufficient lime, mainly for economic reasons.

This booklet aims to help New Zealand pastoral farmers, including dairy farmers as well as those breeding and/or finishing sheep, beef and deer, to understand the vital role of lime. It describes how lime works in the soil and its effects on pasture production. These results are used to estimate the effects on animal performance and farm revenue. The extra farm income can then be offset against the investment in lime application to assess the overall economic benefit.

This booklet is, of necessity, a general account of the role of lime. Every farm is different and there is no golden rule for all areas or even all farms within a region. When the relationships between lime and farm performance are understood, it is possible to work out whether lime is likely to increase profit on your farm, or special purpose areas within it. If in doubt, seek the opinion of your Ravensdown Agri-Manager or Ballance Nutrient Specialist or qualified agricultural consultant.

Why do soils need lime?

The hydrogen ion (H^+) concentration in soils, the sole cause of soil acidity, is measured in a pH scale ranging from 0 to 14. Acids have pH levels between 0 and 7 and alkalis have a pH range from 7 to 14. The pH levels of New Zealand pastoral soils generally fall within the range 4.5 to 7.0.

In their unmodified state, peat soils and highly weathered soils (e.g. podzols) have pH levels as low as 4.5. In contrast, soils derived from limestone (e.g. rendzinas) may have natural pH levels above 7.0. In their virgin state, the pH of most mineral soils fall in the range 5.0 to 6.0.

The legume-grass based pastoral system modifies the natural soil pH. This is because some plant and soil processes produce acids (H^+). The most important of these are: organic matter accumulation, mineralisation of organic matter to nitrate N and clover N fixation resulting in the leaching of nitrate N. Of course, there are other acid-producing processes and reactions, such as during the dissolution of most N and elemental S fertiliser, but these effects are relatively minor compared to the processes listed above. Of these fertilisers, sulphate of ammonia (SOA) is the most acidifying. Urea and diammonium phosphate (DAP) are much less acidifying and differ in their effect depending on other factors such as the rate of nitrate leaching.

The net effect of these processes is that acids accumulate in the soil, decreasing the soil pH. Lime, because it is an alkali, neutralises this acidity, reversing the process of acidification. The rate of acidification and hence the amount of lime required for neutralisation depends primarily on the soil productivity. Very productive legume/grass pastures producing 15-18,000 kg DM/ha/yr may need up to 400-500 kg lime/ha/yr (i.e. 2.0-2.5 tonnes/ha every 5 years) to neutralise this acidity and hence maintain the soil pH. In comparison, a hill country pasture may need only 100-200 kg lime/ha/yr.

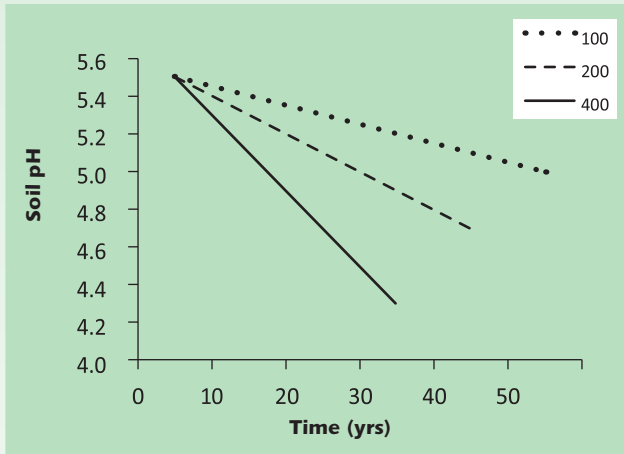
If no lime is applied, the soil pH will decline over time and the rate of decline will depend on the rate of acidification (Figure 1). For example, in intensive systems (e.g. dairying) the pH may drop below 5.0 within a decade from a starting point of 5.5, in the absence of lime application. In contrast this may take several decades in less intensive situations such as hill country.

In practice, acidification is not a problem in most intensive systems such as dairying because liming is generally economic. However capital lime application (i.e. lime to raise

soil pH to 5.8-6.0) and maintenance applications may not be economic in some more extensive situations, such as the drier hill country and in the South Island High Country (see ‘The economics of liming’).

In the absence of lime inputs and given sufficient time, soils will become too acidic, (pH < 5.0-5.2) to grow a legume dominant pasture. Legumes are more sensitive to acidity than grasses and thus as the soil becomes more acidic, legume production will decline and with it inputs of symbiotic N fixation, leading to lower pasture production. For these reasons, lime application (either capital or maintenance) is an essential management practice to counter the effects of soil acidification.

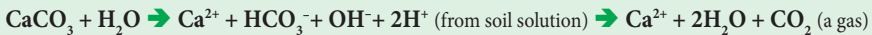
Figure 1: The predicted decline in soil pH for three different soils which have different rates of acidification, assuming an initial pH of 5.5. The liming requirement per year to neutralise the acidification of the different soil is shown in kg lime/ha/yr.



How does lime work?

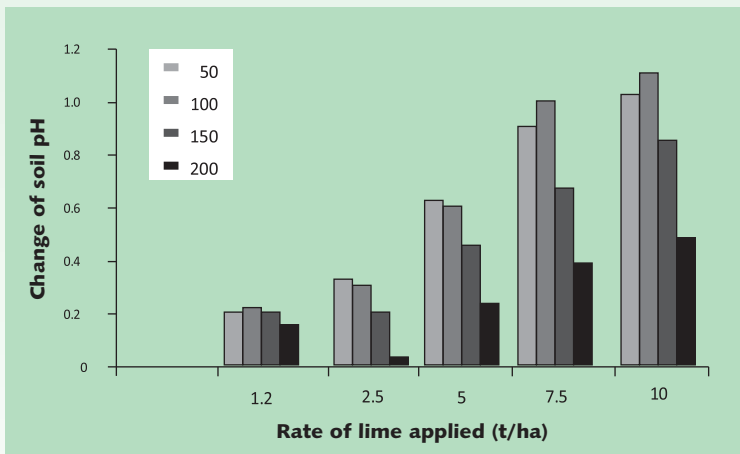
Primary effect of lime

Lime (ground limestone) contains calcium carbonate together with a small proportion of various impurities (see 'Liming Materials' for more details). When lime comes into contact with soil acids, the calcium carbonate gradually dissolves in the soil moisture. In New Zealand, soils generally have plenty of Ca for optimal pasture production, either from soil weathering or superphosphate (20% Ca) and lime (40% Ca) applications. The active ingredient (i.e. the reason we apply lime) is the carbonate that reacts with water in the soil producing an alkali (OH⁻) that neutralises the acid (H⁺) to form free calcium, water and carbon dioxide. As the acidity is neutralised the pH increases.



Lime is only slowly soluble (see 'Liming Materials') and its effects are not immediate, unless very finely ground (< 0.1 mm particle diameter). When the lime first dissolves, a lift in pH occurs immediately around the lime particles, then spreads over time across the soil by diffusion and then down through the soil by leaching. The more lime that is applied, the greater these effects (Figure 2).

Figure 2: The effect of rate of lime applied on soil pH at four depths (50, 100, 150 and 200 mm) five years after applications.



The primary effect of liming is to change the soil pH which in turn has an effect on one or more mechanisms that cause a response.

Mechanisms of lime response

Increased biological activity

Soil organisms, both micro (e.g. bacteria) and macro (e.g. earthworms) become more active as the pH rises up to about 5.8-6.0. This in turn increases both the rate of accumulation and breakdown (cycling) of soil organic matter. Since organic matter contains nitrogen (N), phosphorus (P) and sulphur (S) as well as other nutrients, these can become more available for plant growth. N is the major limiting nutrient in pastoral soils and hence pasture responses to liming are often expressed as N responses. Increased biological activity in the soil has other benefits such as improving soil structure, making the soil more friable (easier to work) and permeable (increasing air and water holding capacity and decreasing surface runoff).

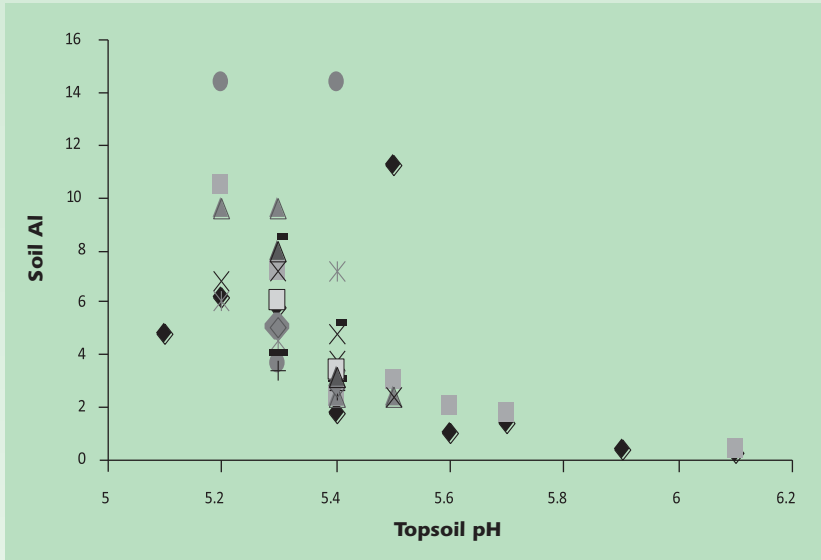
Increased biological activity is the major mechanism by which liming can increase pasture growth in our organic rich soils in the pH range 5.5 to 6.0.

Decreased aluminium and manganese toxicity

As the soil pH decreases below 5.5 the amount of plant available aluminium (Al) (Figure 3) and manganese (Mn) increases. Small amounts of these elements are toxic to plants, especially clovers and other legumes. Aluminium toxicity restricts the growth of plant roots, reduces the plant's ability to take up nutrients and moisture, and reduces the formation of nitrogen-fixing nodules on legume roots. Manganese toxicity is less common in New Zealand. The reduction in aluminium toxicity is the major mechanism by which liming increases pasture growth in the pH range 5.0 to 5.5.

Soil Al is measured as an extraction by CaCl_2 or KCl. The critical toxicity range for CaCl_2 extraction is 3 – 5 ppm and for KCl extraction it is 1-2 me/100g, both of which occur at soil pH below 5.5 in the top 75 mm of soil. The relationship between soil pH and Al (CaCl_2) is shown in Figure 3 below. However, because there is a good relationship between soil Al and pH and the response to lime to address soil Al is more variable than the response to increase pH, the best practice is to increase soil pH up to or above 5.5 by applying 1 t/ha of lime per 0.1 pH unit required (e.g. 5 t lime/ha to raise pH from 5.0 to 5.5).

Figure 3: The effect of topsoil pH (0-75 mm) on soil exchangeable aluminium extracted by CaCl_2 (ppm) for individual soil samples at different sites (with sites represented by the symbols).



Increased molybdenum availability

The plant availability of molybdenum (Mo) increases as the soil pH increases. Molybdenum is an essential trace element for clovers and thus on Mo deficient soils, mainly those derived from greywacke, liming can result in an increase in clover growth and nitrogen fixation. Prior to the discovery of Mo deficiency and its addition as a trace element in fertiliser, this was a major reason for the beneficial effects of lime on many sedimentary soils.

Increased phosphorus availability

On a small number of select soils - e.g. some of the drier sedimentary soils of the East Coast and recent Northland soils, liming can increase the availability of soil P for a short period. This is due to the breakdown and increased plant availability of both organic and inorganic P. This effect is commonly referred to as P-sparing but it is not large and is not predictable. For these reasons fertiliser P inputs should not be reduced because of liming.

Improving soil moisture status

Under dry soil (hydrophobic) conditions, water is repelled by organic compounds at the soil surface and does not as readily infiltrate the soil. Liming reduces the severity of this mechanism and increases the soil moisture status of the soil in summer and autumn.

Induced manganese and zinc deficiency

As the soil pH increases over 6.5, manganese and zinc (Zn) become increasingly unavailable. Thus, over-liming can depress plant growth. Such over-liming is uncommon but has been recorded on coarse textured soils in the South Island.

Determining lime requirements

The optimal pH for pastures is pH 5.8-6.0 (see 'How does lime work'). For mineral soils, the amount of lime to achieve this pH - the lime requirement - can be readily calculated from the initial soil pH and the amount of organic matter (%C) in the soil:

$$\text{Lime requirement (to reach pH 6.0) (t/ha)} = 28.7 - (4.8 \times \text{initial pH}) + (0.17 \times \%C)$$

You can get a fairly good idea of the lime requirement from the initial pH without the %C. The calculation becomes:

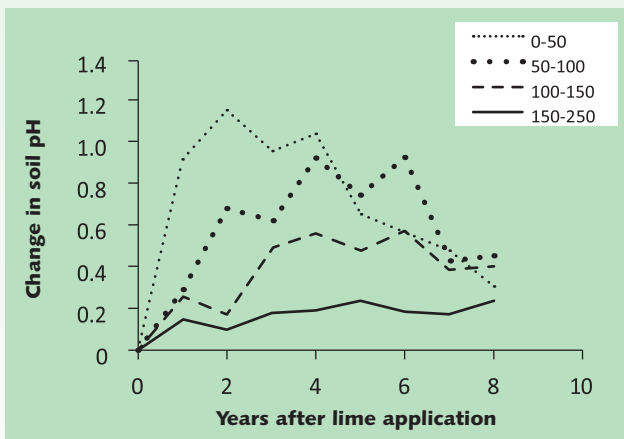
$$\text{Lime requirement (t/ha)} = 28.7 - (4.8 \times \text{initial pH})$$

A handy rule of thumb is that 1 tonne/ha of good quality lime i.e. 80% CaCO₃ or better will raise mineral soil pH by 0.1 units.

The duration of lime effects

Lime is sparingly soluble and therefore it takes time for the lime to dissolve in the soil and move down the soil profile. Figure 4 shows the effect of lime (5 tonnes/ha) on the change in soil pH at four soil depths over time.

Figure 4: The effect of time on soil pH at four depths following liming at 5 tonnes/ha.



In this example the maximum change in soil pH in the 0-50 mm depth occurred 2 years after application. It also takes time for the effects of lime to move into the soil. The maximum change in the pH in the 50-100 mm depth did not occur until 4-6 years following application.

For any given acidification conditions discussed above, the main factor affecting the duration of the lime response is rainfall and/or irrigation, or more specifically the amount of water that moves through the soil profile. For this reason, the duration of the effects of lime i.e. the time that a single application of lime will keep the pH above the pre-limed soil pH, can be determined from rainfall/irrigation information.

Duration (in years) equals:

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

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

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

Maintaining Soil pH

Once optimal pH is achieved, ongoing inputs of lime will be required to maintain the level. Typical practice where liming is economic is to apply lime at 2.5 tonnes/ha to a proportion - a third, fourth or fifth of the farm annually. The proportion will depend on the underlying rate of acidification. In high producing, high rainfall areas for example, this may be every 4 years (i.e. equivalent to 625 kg lime/ha/yr). Alternatively, a lower rate of maintenance lime can be applied annually to the whole farm. In drier situations lime at 2.5 tonnes/ha may be required every 5-6 years (or 400-500 kg lime/ha/yr). In more extensive situations, where the rate of acidification is lower, such as hill country, the amount of lime required to maintain soil pH is much lower say 100-200 kg lime/ha/yr.

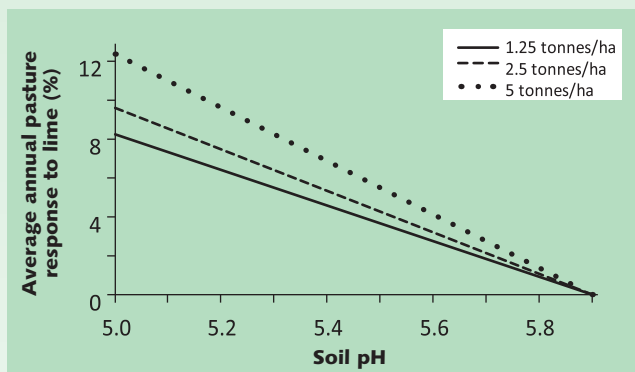
The best way to evaluate the need for further liming is to have a good soil testing plan so that the soil pH is monitored on an ongoing basis, and to use decision support software such as OverseerFM, which has an acidification model to assist with the decision for applying maintenance lime as required.

Pasture responses to lime

By increasing the soil pH, lime influences pasture growth and production in several ways.

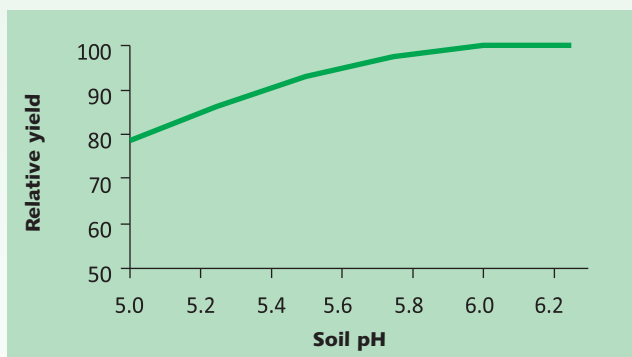
Many pasture trials have measured the net effect of liming on pasture production. From these trials, the relationships between the pre-lime soil pH and the percentage increase in annual pasture growth has been determined (Figure 5) for three rates of lime. The lower the initial pH, and the higher the lime rate, the greater the pasture response. Note that when the initial pH is about 5.9, no response to liming is predicted. It is for this reason that the optimal pH for pastoral mineral soils is set at 5.8-6.0.

Figure 5: Relationships between soil pH and average annual pasture response (%) to lime at 3 application rates.



This can be expressed the same way as the 'calibration' curves for the major nutrients P, K and S:

Figure 6: Approximate pasture yield response to changes in soil pH (expressed as a percentage of potential yield).



These relationships are not exact because there are many other factors that can affect the pasture responses to lime.

These include:

- Stocking rate: generally, as the stocking rate increases, so too does the pasture production response to lime.
- Pasture composition: pasture species differ in their tolerance to acidity and soil Al and this can affect the size of the response to lime.
- Soil fertility: liming has many effects on soil nutrients. The presence or absence of essential nutrients can affect the response to lime.

Seasonality of lime responses

The lime responses referred to in Figure 5 are increases in annual pasture production. In fact, pasture responses to lime are typically seasonal as shown in Table 1 below.

Table 1: Mean seasonal increases in pasture production (%) for a range of lime trials.

Trial number	Spring	Summer	Autumn	Winter
1	2	13	0	-5
2	12	19	40	32
3	-1	10	36	10
4	3	7	14	18
5	15	27	6	8
6	-2	3	7	1
Mean	5	13	17	11

The greatest responses usually occur in summer or autumn, regardless of when the lime is applied. The smallest response is usually in spring.

This seasonal pattern is consistent for various lime application rates and occurs whether the overall response is large or small. The size of the responses in Table 1 varies because the trials cover a range of lime rates on soils with different initial pH.

The reasons for the seasonal responses are not clear but may be related to the interaction between soil acidity and pasture composition. Different pasture species have different tolerances to acidity and hence they respond differently to lime. They also have different seasonal growth cycles. For example, legumes are more sensitive to acidity than grasses and are most active in the summer and autumn. Similarly, because aluminium toxicity negatively affects root growth there is likely to be an interaction between soil moisture

conditions and responses to lime. Also hydrophobic conditions in the soil are more likely to occur in dry summer and autumn conditions.

The seasonal response has important implications for farm management. Liming may increase the amount of feed available for flushing ewes and finishing young stock to sell before winter.

Although liming does not directly increase the spring feed supply, you may be able to carry more autumn feed into winter and thus achieve higher spring pasture cover for lambing and/or calving.

Chemical composition

Liming generally increases the uptake of calcium and molybdenum by plants and decreases magnesium and manganese uptake. For the most part, it has little practical effect on other elements such as nitrogen, phosphorus, sulphur, potassium, sodium, copper, boron and cobalt when the soil pH is between 5.0 and 6.0.

Botanical composition

Pasture species have differing tolerance to soil acidity and Al levels. Generally, low producing grasses (e.g. browntop, chewings fescue) are more tolerant than high producing grasses (e.g. ryegrass) that in turn are more tolerant than legumes (e.g. white clover). Thus, liming usually encourages the higher producing pasture species such as legumes and ryegrass at the expense of lower fertility species like browntop and fescue. In addition, the specific effect of liming also affects pasture composition. On molybdenum deficient soils liming greatly increases clover growth, but if liming increases soil nitrogen availability for a short period then this is expressed principally through an increase in the grass component of the pasture.

Animal responses to liming

As a result of its effects on pasture production and pasture botanical and chemical composition, liming can affect animal production and health.

Animal production

Many trials have measured the effects of liming on both pasture and animal production and these trials show that the size of the increase in animal production (milk, live weight, wool weight) is related to the size of the pasture response. In the absence of pasture production responses to lime, animal responses to liming are unlikely.

Furthermore, several trials have shown that liming high-quality ryegrass-clover pastures does not directly affect the nutritional value of pasture or pasture utilisation. Thus, it is concluded that the primary effect of lime on animal production in these high-quality pastures is through an increase in the amount of pasture available.

Liming can alter the botanical composition of pasture, as discussed, and this can affect animal production, and pasture palatability and utilisation. For instance, an increase in the clover content in the pasture will increase its nutritional value. An increase in the proportion of high producing ryegrasses will result in a more palatable pasture.

Some trials show that production responses to lime (both pasture and animal) are linked to stocking rate. The biggest responses occur at high stocking rates. This is attributed to two factors: at higher stocking rates pasture is kept in a vegetative state allowing the pasture to better respond to the rise in soil pH. Also, pasture utilisation is higher at higher stocking rates.

This does not mean you must have a high stocking rate for liming to be beneficial. It does, however, emphasise that good grazing management and high pasture utilisation are required to maximise value from the response.

Animal health

One of the often discussed aspects about lime is that it improves animal health. This is true in as much as an increase in pasture growth may result in better feed, and hence healthier animals. But liming can have specific negative effects on animal health if care is not taken in the rate, frequency and timing of its use.

Reduced magnesium and increased calcium

Less magnesium (Mg) and more calcium (Ca) in pasture plants may increase the risk of clinical hypomagnesaemia (grass staggers) in lactating dairy and beef cows. These effects are greatest in late winter and spring, coinciding with late pregnancy and early lactation. Lime should not be applied later than mid-autumn for spring calving cows, as excess Ca from liming may also induce hypocalcaemia (milk fever), through suppressing the lactating animal's ability to mobilise bone Ca reserves.

Supplementation of Ca, using lime flour (finely ground limestone), if necessary, should only begin immediately post-parturition (after birth).

Increased molybdenum

Molybdenum (Mo), in the presence of sulphur and iron, interferes with the availability of copper (Cu) to animals. High levels of molybdenum (> 1 ppm) increase the risk of an “induced” copper deficiency. For this reason it is important to monitor pasture Cu and Mo levels and animal liver Cu levels.

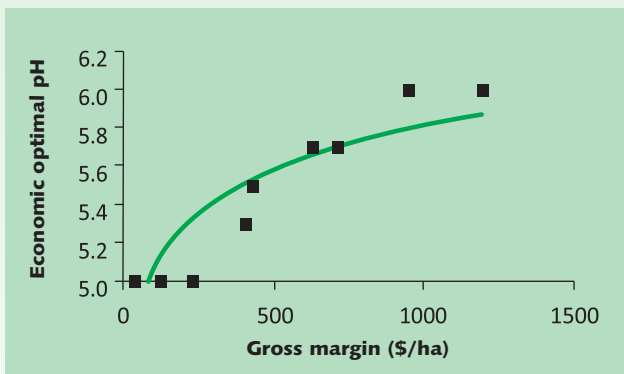
The economics of liming

As shown earlier, the biological optimal soil pH for pastures is 5.8-6.0. At this pH, pasture production is optimised. However, it is not always economic to lime to this pH level. The economics of liming depend on the dollar value of the benefits of liming relative to the cost of liming. The benefits are a function of the size of the pasture response, and hence animal benefit, plus the duration of the liming effect. The costs include the purchase, transport and spreading of the lime. This section applies to the economics of lime on mineral soils. Peat soils are dealt with in the next section.

Effect of gross margin

The most important factor determining the economics of lime is the profitability of the farming enterprise and that, in turn, depends on the intensity of the operation (the stocking rate) and the value of the resultant animal products. A measure of this profitability is the gross margin per hectare (gross revenue – direct costs). Using modelling the relationship between gross margin/ha and the economical optimal soil pH can be derived (Figure 7).

Figure 7: The relationship between gross margin/ha and the economic optimal soil pH.



The more profitable the farm, the higher the economic optimal pH will be. Most dairy farms have gross margins greater than \$1000/ha and hence the economic optimal pH is the same as the biological optimal pH, 5.8-6.0.

Intensive sheep and beef operations typically have gross margins in the range \$500 - \$1000/ha and hence it is profitable to apply capital lime to raise soil pH to about 5.6-5.7. For typical hill country sheep and beef operations with a rainfall greater than 1000 mm/yr (e.g. Central North Island hill country), the gross margin will be around \$500/ha for which the economic optimal pH is about 5.5. For less intensive operations such as in the drier hill country and South Island high country it is economic to apply capital lime only up to around pH 5.0, except on speciality pastures or crops, silage, hay and finishing pastures.

The stocking rate effect

Stocking rate has a very large and direct effect on the gross margin. As the stocking rate increases, so too does the gross margin/ha and thus the net present value of liming increases (the net present value is the sum of the annual profits from liming over the duration of the lime response which are then discounted for the effect of inflation).

If the initial pre-limed soil pH is 5.0 then capital lime is profitable (i.e. net present value > 0) for stocking rates of 8 SU/ha and above. At an initial pH of 5.2, capital lime only becomes economic if the stocking rate is greater than 10 SU/ha assuming normal gross margins per stock unit for hill and high country farms. On a similar basis, if the initial soil pH is 5.4 then it is never economic to lime irrespective of the stocking rate.

Priorities

The question frequently raised is the order of priority between lime and fertiliser. The following generalised guidelines can be applied, although the priority on any individual farm is where the largest financial gain is to be made.

- On very acid soils (pH 5.0 or less), such as peats and highly weathered soils, lime together with fertilisers, is essential for pasture establishment and maintenance.
- On soils where the pH is below economic optimum (between 5.0 and 5.8) and the goal is to maximise production, apply both lime and fertilisers. This will be the case for most dairy farms.
- On soils where pH is below the economic optimum (between 5.0 and 5.8) and finances are limited, the top priority must be correction of any nutrient deficiencies. Yield responses to lime are generally much lower (i.e. only 0 to 10%) than the yield responses to correction of nutrient deficiencies (often greater than 50-100%). This will apply to most sheep and beef farms.

This is illustrated in the table below for hill country where lime and fertiliser has to be aerially applied:

	Olsen P < 15	Olsen P > 15
pH < 5.5	Apply P and S	Apply lime
pH > 5.5	Apply P and S	Apply P and S

- On sheep and beef farms where the pH is below economic optimum (between 5.0 and 5.8) and the soil nutrient levels are optimal, the economic optimal soil pH should be determined (see your fertiliser consultant) to decide how much lime to apply.

Lime for peat soils

Peat soils are a special case. True peat soils have more than 40% organic carbon in the topsoil while peaty loams have 20 to 40% organic carbon. Organic soils (peats) do not have the typical “minerals” i.e. clays, silts and sands found in mineral soils and their responses to liming are, therefore, quite different. They often have a very low natural pH if they have not been limed before.

Pasture responses to liming

If the topsoil pH (at depth 0 to 75 mm) is already above 5.0, responses to liming will be quite small. Larger responses are likely if soil pH is less than 5.0 in which case liming is usually economically worthwhile for pasture development and maintenance.

Subsoil liming

The subsoil pH (at depth 75 to 150 mm) is usually very low, often only 3.5 to 4.5. For good pasture production, a subsoil pH of at least 4.5 is best but lime applied to the surface of peat soils does not affect the subsoil. Lime must therefore be incorporated into the soil to at least the 150 mm depth.

Table 2 shows changes in pasture production found after incorporating lime in a newly sown, raw peat. Subsoil liming improves the pasture performance in dry periods as plant roots can then penetrate the deeper soil layers and obtain more moisture.

Table 2: Effect of lime rate and application method on pasture production (kg dry matter /ha) on a Moanatuatua raw peat.

Application method	Lime application rate (tonnes/ha)					
	0	2.5	5.0	10	15	20
Surface applied	2500	3500	4300	3700	3800	3000
Incorporated	-	4700	6300	6400	6900	6800

Target pH for peat soils

When establishing new pasture, topsoil pH (depth 0 to 75 mm) should be at least 5.0 and subsoil pH (depth 75 to 150 mm) should be at least 4.5 for best performance. Cultivation brings low pH subsoil up to the surface so you may need extra lime when renovating old pastures.

Lime requirements

The amount of lime needed to raise pH on peat soils depends on the stage of development, its previous history and the application method you use. Table 3 shows the lime needed to raise pH under various conditions. Note that these examples apply only to peat soils in the Waikato Basin. No information is available for other regions but they would be expected to be similar.

Table 3: Lime required to raise pH of organic soils by 1 unit.

Application method	Soil depth (mm)	Stage of peat development	
		Raw Peat	Previously developed peats and peaty loams
		Lime required (tonnes/ha)	
Surface applied	0-75	-	9
	75-150	-	No effect
Incorporated	0-75	7	16*
	75-150	17	34*

**Note that for raw peat deep liming is necessary. Also, the requirements for previously developed peats is nearly double that for raw peats. The explanation for this is that as peats are developed for pastoral farms, they become considerably denser. Hence at a given pH, there is more acid per unit volume of soil for these denser peats, requiring more lime to neutralise the acid.*

The following examples may help you apply these figures.

Example 1: Raw peat, pH 4.0, deep liming required

The pH should be raised by 1 unit (to 5.0) in the topsoil and by 0.5 units (to 4.5) in the subsoil. It would take 17 tonnes of lime per hectare to raise the subsoil pH by 1 unit (from Table 3), so you need to incorporate 8.5 tonnes per hectare to the 75-150 mm depth to raise it by 0.5 units.

The topsoil need 7 tonnes per hectare to raise the pH by 1 unit, so you will need 7 tonnes/ha incorporated into the 0-75 mm depth.

Example 2: Developed peat, pH 4.5, deep liming required

The pasture will be re sown to allow for incorporating lime into the soil.

Topsoil pH needs to rise by 0.5 units but subsoil pH is adequate.

Raising the topsoil pH by 1 unit would require 16 tonnes of lime per hectare so you need $16 \times 0.5 = 8$ tonnes per hectare, which is to be worked into the soil to a depth of 75 mm.

Example 3: Developed peat, pH 4.5, surface applied lime

The pasture does not need to be re sown since lime will be applied to the surface.

Topsoil pH needs to be lifted 0.5 units and will need $9 \times 0.5 = 4.5$ tonnes lime per hectare.

Maintenance lime requirements for peats

There is no information available about the lime required to maintain pH on developed peat soils. Use soil testing to monitor pH every one to two years and apply lime as required to reach target pH levels as discussed above. You will need to take separate deep samples of subsoil (75-150 mm) as well as the usual 75 mm cores of topsoil.

Liming materials

Agricultural lime

By far the most common liming material is agricultural lime, which is ground limestone rock containing calcium carbonate. As a natural product, the quality of lime can vary considerably. There are two factors which determine the quality of agricultural lime: the carbonate content and the particle size (fineness of grinding).

Carbonate content

The carbonate content of New Zealand limestones varies between 60-90% (Table 4). Because the carbonate is the 'active ingredient' in lime, the price of lime could be based on the calcium carbonate content.

Impurities may include trace elements such as molybdenum, boron, cobalt, copper and zinc. These are usually present in such small amounts that they do not provide any pasture production or animal health benefits when lime is applied.

Table 4: Typical range of carbonate contents (neutralising values) of limestones from various regions

District	Calcium carbonate content (%) or Neutralising value
North Auckland	65-70
South Auckland, King Country	80-95
Remainder of North Island	75-90
Nelson	85-100
Marlborough	75-90
Westland	75-90
Canterbury	75-90
Otago	85-95
Southland	75-90

Because lime is a relatively cheap product (compared to most fertilisers), transport costs can be a major component of the on-ground cost. For this reason, it is normally best to source lime from the nearest location assuming that the on-ground cost reflects the total neutralising content applied.

Fineness of grinding

The rate at which lime dissolves depends largely on the surface area exposed to soil moisture and the surface area is directly related to the particle size. Fine lime has a much

greater surface area than coarse lime and so it dissolves faster. At any given weight, halving the particle size doubles the surface area. Because it dissolves more rapidly, fine lime reacts more quickly and provides faster changes in soil pH and pasture growth in a lime-responsive soil. However, the total effect on soil pH is similar to that from coarser lime because fine lime has a shorter duration of effect. Very coarse lime is only very slowly soluble in the soil (Table 5).

Table 5: The effect of particle size on the rate of dissolution of limestone.

Mesh number	Mean diameter (mm)	Proportion (%) dissolved in 6 months
10-20	1.2	11
20-40	0.56	22
40-80	0.23	60
80-150	0.12	95

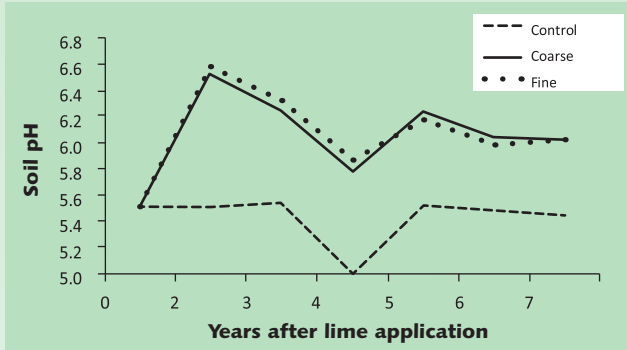
It follows that a large proportion of a given lime must be very fine if it is to fully dissolve in the year of application. In practice, ground limestones contain a mixture of particle sizes (Table 6).

Table 6: Particle size of two typical commercial limestones

Size range	Coarse (93% calcium carbonate)	Fine (86% calcium carbonate)
>2.0 mm	0	0
>0.5 mm	48	27
<0.5 mm	52	73

However, despite their differences in particle size, these two limestones have a similar effect on soil pH (Figure 8).

Figure 8: The effect of coarse and fine lime on soil pH over time.



Based on experiments such as this, it has been concluded that for most agricultural purposes all limestones applied at the same rate of calcium carbonate are equally effective providing:

- at least 50% passes through a 0.5 mm sieve
- not more than 5% fails to pass through a 2 mm sieve

Note that when lime is ground to this standard it will contain some material finer than 125-200 microns and therefore will have some effect on soil pH in the short term (6-12 months) but the maximum effect on soil pH will typically not be reached until 18-24 months following application.

Reactivity

The reactivity of limestones depends on the hardness of the particles and their porosity. This is related to the carbonate content whereby the higher the carbonate content the harder and less porous the particles. For example, pure calcium carbonate formed under heat and pressure is marble, which is a very hard rock. A limestone containing 60% carbonate can be very readily crushed. However there has been found to be no difference between hard and soft lime with respect to their effect on soil pH.

Other liming materials

There are other materials that have a liming action - i.e. that can raise soil pH.

These include:

Burnt and slaked lime

When limestone (calcium carbonate) is heated (burnt) it forms calcium oxide. When water is added to the oxide, calcium hydroxide (slaked or hydrated) lime is formed.

Both of these materials are more soluble and hence have a much faster effect than limestone. They are also more concentrated (have a higher neutralising value) than limestone and hence less is required to achieve the same change in soil pH. However, they are more expensive per unit lime equivalence because it costs money to burn the lime. Additionally, they are extremely caustic materials and if ingested by grazing animals, can cause serious illness or even death.

Dolomite

Dolomite contains both calcium carbonate and magnesium carbonate and is typically harder than most limestones. It therefore needs to be finely ground to be as effective as limestone. Responses to dolomite are similar to those from lime, when compared on an equivalent carbonate basis, but dolomite also supplies magnesium.

Comparison of liming materials

A range of liming materials is compared in Table 7. Although ground limestone is the least concentrated (i.e. low neutralising value) it is generally much cheaper on the ground than other liming materials.

Table 7: Comparison of neutralising value and amounts of different liming materials to apply.

Product	Lime neutralising value (%)	Amount to increase pH by 0.1 units (kg/ha)
Agricultural Limestone	90	1111
Dolomite	98	1020
Burnt Lime	178	560

Some less commonly used alternative products to agricultural lime, (e.g. kiln dust), can contain high concentrations of heavy metals and asbestos and these should be checked before use.

Checking lime quality

Fertmark™ operates a quality assurance scheme on behalf of farmers. Lime producers can register their products and have them tested and audited to ensure they meet the appropriate standards. This scheme is voluntary. If in doubt only use Fertmark registered products or have the lime analysed at a laboratory - e.g. the lab that does your soil tests.

Fertmark has a different standard for aerial agricultural lime and agricultural lime, which are described as follows.

Aerial agricultural lime

Ground limestone rock with a minimum lime equivalent of 65% by weight of CaCO_3 .

In addition, the material shall meet the Civil Aviation Authority requirement that not less than 80% of the load shall be able to be dumped from a conventional agricultural aviation hopper in less than 5 seconds.

Ground limestone which has not less than 95% by weight able to pass through a 2.00 mm sieve, and not less than 40% by weight able to pass through a 1.0 mm sieve, and not more than 2.5% able to pass through a 0.5mm sieve shall be deemed to meet this requirement.

Agricultural lime

Ground limestone rock with a minimum lime equivalent of 65% by weight of CaCO_3 .

Not less than 95% by weight shall be able to pass through a 2.00 mm sieve, and not less than 30% by weight shall be able to pass through a 0.5 mm sieve.

Applying lime

Having decided to apply lime and chosen the product there are two further issues to consider.

When to apply lime

The timing of lime applications depends on some specific circumstances. Some useful guidelines are as follows:

Pasture establishment

If the soil pH is low (< 5.5 on mineral soils and < 5.0 on peat soils) lime inputs are essential prior to sowing for good establishment. At higher pH levels, capital liming may not be economic, but apply maintenance lime.

Pasture maintenance

Lime application for maintaining soil pH may be undertaken on either an annual basis at low rates over the whole farm, or on a rotational basis around the farm (e.g. a third of the farm every three years) at a higher rate suitable for neutralising the acidification that has occurred over the previous two years. It is considered preferable to apply lime annually to maintain soil pH to keep pasture productivity near its maximum potential rather than let the soil pH drop below the optimal range before lime is applied. Avoid applying lime to pastures from late autumn to early spring as this may cause metabolic problems for lactating animals.

Placement of lime

The Spreadmark™ Code of Practice provides a placement quality assurance programme. The scheme accredits fertiliser spreading companies, both aerial and ground spread, with the view to ensuring product is spread uniformly and with the least environmental harm or disturbance.

Spreadmark identifies that a number of product characteristics affect flowability and applies information on these characteristics to achieve appropriate settings and bout widths for each product.

The ideal placement depends on the soil type:

Mineral soils

The pH in mineral soils usually, but not always, increases with soil depth so there is less need for lime in the deeper soil. Surface-applied lime is as effective, and much cheaper, than lime incorporated into the soil. But where soil pH decreases and Al increases with depth, incorporating lime during cultivation is beneficial especially for deep rooting plants such as lucerne.

Peat soils

The pH usually decreases with soil depth and the subsoil may be very acid. There may be major benefits to incorporating lime into the soil. See 'Pasture responses to lime' for more details about liming peat soils.

Lucerne

The bacteria that nodulate lucerne are sensitive to soil acidity and therefore lucerne ideally requires a higher soil pH of 6.2-6.4 in the top 150 mm. To achieve this soil pH by the time that the lucerne is sown, high rates of lime (2.5 – 5.0 t/ha) have to be applied 6-12 months before establishment and incorporated into the soil when cultivating. Except under high rainfall, surface-applied lime only moves slowly down through the soil.

Cropping

There is more detailed information in the booklets "Fertiliser use on New Zealand Forage Crops" and "Managing Soil Fertility on Cropping Farms" but generally cropping soils require a soil pH of 6.0-6.2 at sowing. As for lucerne this could require incorporation of lime 6-12 months before sowing.

Liming strategies on extensively-farmed land

In both the North and South Island there are farms or parts of farms where despite development, climatic and soil limitations restrict stocking to rates below 5 SU/ha. Here soil pH is generally less than 5.2 and the application of lime is not economic because of one or more of the following reasons:

- Animal production is at lower levels
- The farm is a long distance from a lime quarry leading to high transport costs
- The lime has to be aerially applied which is much more expensive than ground application

In this situation there are various strategies available to optimise the lime application or to adapt the choice of pasture species to the acidity of the soil. These include:

- Hill country varies in topography and it can be more profitable to differentially apply lime to south aspects and easier slopes where there is more legume.
- If some parts of the farm that have low soil pH and high soil Al have higher rainfall (average annual rainfall > 1000 mm) then pastures may be able to establish and be reasonably productive with low rates of lime (0.5-1 t/ha). Better soil moisture means that high subsoil Al restricting root growth is not as critical.
- Where soils are acid and rainfall is low, legume species such as Lotus, and subterranean, Caucasian, Persian and gland clovers will perform better than white clover or lucerne.

Environmental Considerations

Greenhouse gases

Liming contributes to the emission of greenhouse gases both directly and indirectly as outlined below:

Carbon dioxide is a greenhouse gas and a direct product of the reaction of lime with the soil, making up about 1.6% of the total NZ agricultural inventory for emissions. Because the carbon dioxide is a direct result of the neutralising process (see the equation on page 7), the national inventory calculates this contribution using a simple emissions factor per tonne of lime applied.

Therefore, care should be taken not to apply excess lime above the target soil pH range.

Methane from ruminant animal digestion process and nitrous oxide emissions from urine patches are powerful greenhouse gases which make up the majority of agricultural emissions. Therefore, an indirect effect which increases overall greenhouse gas emissions occurs if liming results in increased feed consumption by ruminant animals.

Cadmium

Cadmium (Cd) derived from application of P fertilisers gradually accumulates in agricultural soils. It can be taken up by plants and this provides a pathway to the food chain. Food Standards provide for a safe level of consumption over a lifetime, and an occasional mild exceedance is of no health consequence. However, if food standards are exceeded, it can pose a potential trade threat. Cadmium does not accumulate to any appreciable amount in meat or milk, but does accumulate in offal products, such as kidneys and liver, and in vegetables and grain.

Agricultural lime also typically contains low, trace levels of cadmium, but the advantage of lime is that through raising soil pH, plant uptake of soil cadmium is reduced.

Handling and storage of lime

Recommendations to ensure desirable product performance, handling and flowability characteristics are provided under Fertmark and Spreadmark guidelines.

Because agricultural lime absorbs water (hygroscopic) it is essential that storage before application (especially aerial) is waterproof. Wet lime costs more to apply and also poses a serious safety risk if it does not flow out of the hopper of the topdressing plane. A pilot will not fly aerial agricultural lime if the flowability characteristics are in doubt.

For more information see:

<http://fertqual.co.nz/understanding-the-marks/spreadmark/>

<http://fertqual.co.nz/understanding-the-marks/fertmark/>

