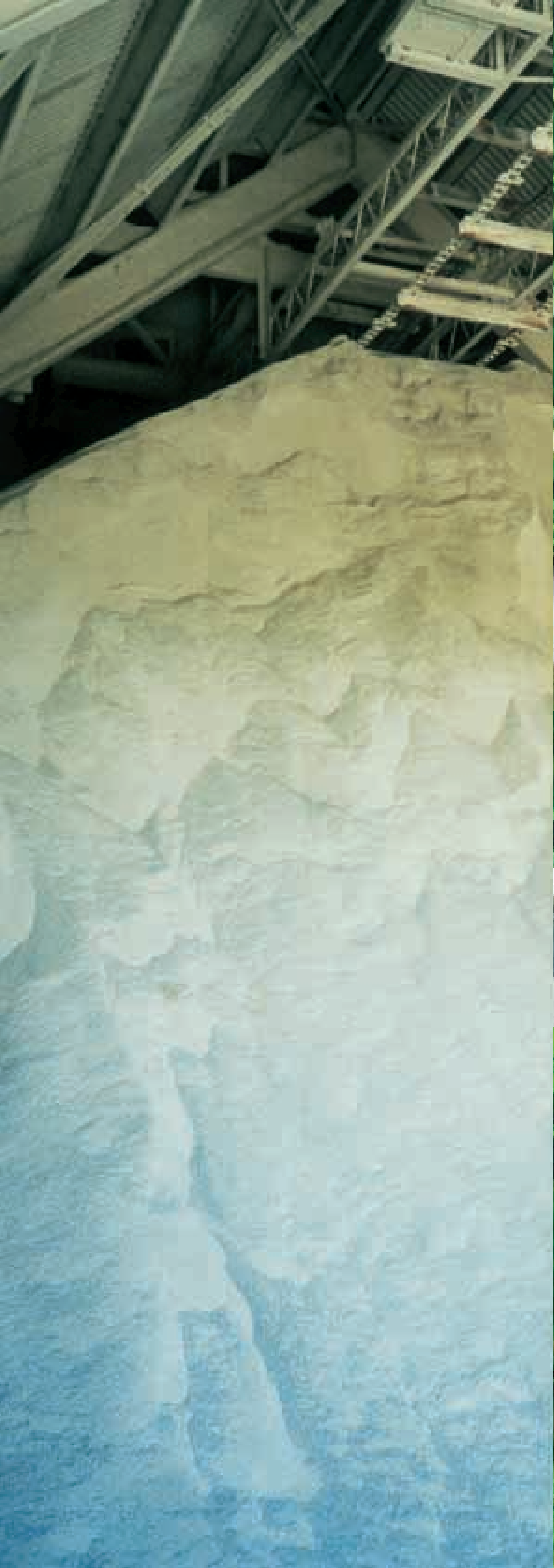
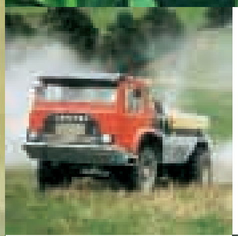
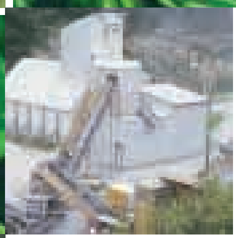
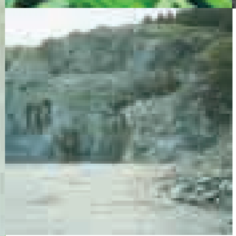
LIME

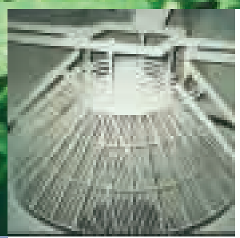
The essential element in New Zealand agriculture

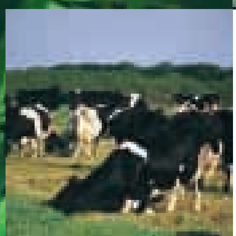












Lime

The essential element in New Zealand agriculture

Compiled for the Northland Lime Millers Association and Associates.

Written by:
Delia Sime B.Sc. (Chem & Enviro.Sc.)
Environmental Planner, Opus International Consultants Ltd.

Graphics by:
Adrian Hill

Edited by:
Mike O'Connor MAgr.Sc. (hons) - Senior Scientist AgResearch, Ruakura.

The Northland Lime Millers Association would like to acknowledge:
The New Zealand Lime Millers Association for their funding assistance and the Hine Rangi Trust for their continued support in funding assistance for the lime trials carried out in Northland.

Table of Contents

1.0	**Introduction**	**5**
1.1	Benefits of liming	5
1.2	Cautions on liming policies	6
2.0	**Soil Acidity**	**7**
2.1	What is soil acidity?	7
2.2	How do soils become acidic?	7
2.3	Why are we concerned about soil pH?	8
2.4	Subsoil acidification	9
2.5	Indications of soil acidity	10
3.0	**Overcoming Soil Acidity**	**11**
3.1	How does lime work to overcome soil acidity?	11
3.2	Liming materials	11
4.0	**Lime Quality - Get the best value for your money**	**12**
4.1	Calcium carbonate content	12
4.2	Fineness of grinding	12
4.3	Transport and spreading costs	12
5.0	**Chemical Composition of Lime**	**15**
6.0	**How Liming Improves Farm Production**	**16**
6.1	Increased pasture production	16
6.2	Expected pasture responses to liming	17
6.3	Liming to improve soil properties	18
6.3.1	Soil moisture	18
6.3.2	Liming to improve soil structure	19
6.3.3	Liming to increase earthworm activity and numbers	19
6.4	Liming supplies calcium to the soil	20
6.5	The effect of liming in reducing toxicities	21
6.5.1	Aluminium toxicity	21
6.5.2	Manganese toxicity	21
6.5.3	Toxic metals	22

6.6	Liming to improve pasture utilisation	22
6.6.1	Changes in botanical composition of pastures	22
6.6.2	Grazing preference	22
6.7	Lime and fertilisers	23
6.8	The effects of liming on the availability of plant nutrients	23
6.8.1	Essential elements in plants and animals	23
6.8.2	Trace elements	24
6.8.3	Nutrient availability as affected by pH of the soil	24
6.8.4	Nitrogen	24
6.8.5	Phosphorus	25
6.8.6	Manganese	26
6.8.7	Molybdenum	26
6.8.8	Copper	27
6.8.9	Boron	27
6.8.10	Calcium	28
6.8.11	Zinc	28
6.8.12	Iron	28
6.8.13	Cobalt	28
6.8.14	Magnesium	28
6.8.15	Potassium	29
6.8.16	Relative frequency of deficiency	29
6.8.17	Nutrient deficiency symptoms	30
7.0	**Soil pH Preferences of Crops**	**32**
8.0	**Loss of Lime From the Land**	**33**
8.1	Drainage losses	33
8.2	Lime losses and soil type	33
8.3	The effects of fertilisers on soil acidity	34
8.3.1	Ammonium fertilisers	34
8.3.2	Urea	34
8.3.3	Superphosphate	34

9.0	**Factors Influencing Pasture Responses to Lime**	**35**
9.1	The natural supply of lime to New Zealand's soils	35
9.2	Calcium availability in the soil	35
9.3	The organic matter content and the pH buffering capacity of soils	35
9.4	Seasonality in pasture growth responses to lime	36
9.5	Effect of the stocking rate	37
9.6	Factors influencing the speed of reaction of lime in the soil	37
9.7	Timing and placement of lime	37
9.8	Spreading lime	38
9.9	Frequency and application - assessing soil nutrient status	38
9.10	Development phase	39
9.11	Maintenance phase	39
9.12	Duration of responses	39
10.0	**Calculating the Desirable Rate of Lime Application**	**41**
10.1	Liming recommendations for pastures on mineral soils	41
10.2	Liming recommendations for pastures on peat soils	43
	Bibliography	**46**

1.0 Introduction

The pastoral industry is New Zealand's main export earner, generating some 23% of all employment and 55% of all export receipts. This industry is highly dependent on sustaining the production of ryegrass-clover pastures. Normal farming practices plus the general leaching of nutrients from the soil leads to acidification and the need to lime soils on a regular basis.

Over the past 30 years, extensive scientific research has been undertaken measuring pasture responses to liming. Field trials conducted by M.A.F., D.S.I.R. and the universities (Massey and Lincoln) have shown that pasture production can be significantly increased with liming.

Farmers who use lime regularly report thicker pastures, less weeds, better clovers, greater earthworm activity, and improved stock health.

1.1 Benefits of liming

The primary reason for applying lime is to increase the soil pH. As a result of the change in pH many changes in soil chemistry and biology occur.

(1) The most important benefit of liming in agriculture is to increase pasture production. Increases in pasture production lead to significant increases in animal production as measured in live weight, wool weight and milksolids.

(2) Liming increases production throughout the whole year but has its largest beneficial effects on pasture production in summer and autumn. This effect has practical implications in that these responses occur at times when feed supplies are critical.

(3) Lime, locally produced at low cost, maximises the return from money spent on fertiliser. Reducing soil acidity may increase the availability of plant nutrients. This is a very significant effect, possibly one of the most important benefits of liming.

(4) Liming stimulates vigorous growth of clovers and other legumes, by reducing the adverse effects of aluminium and manganese and encouraging rhizobia action essential for the formation and functioning of nodules on all legumes.

(5) Liming encourages more productive pasture species, e.g. rye grasses and legumes, at the expense of low fertility species such as brown top.

(6) Liming encourages better pasture utilisation and more even grazing. Through changes in botanical composition of pasture, liming increases the palatability of pastures to stock.

(7) Liming to an optimum pH increases the availability of some important nutrients. These include phosphorus (P), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg) and trace elements like boron and molybdenum.

(8) Liming continues to be effective in the long term. A single application takes approximately one year to achieve maximum effectiveness, and benefits can last up to 6 years and beyond.

(9) Lime helps overcome aluminium toxicity, which is a problem in many soils. Aluminium toxicity inhibits root growth. By overcoming toxicity, roots proliferate and reach greater depth in the soil, encouraging greater pasture growth.

(10) Lime provides calcium, which is essential to plant and animal growth.

(11) The calcium in lime flocculates (breaks up) the clay particles forming a granular structure, which helps aerate a soil. Ideally for good aeration, soils should have at least 15% large pore space.

(12) Liming reduces the tendency of soil to crack in dry weather by improving soil moisture, holding rewetting capabilities.

(13) Liming increases the base saturation of the soil, creating more opportunity to retain nutrients like Ca, Mg and K on the exchange complex in the soil. After applying lime, soil may need less frequent inputs of some fertilisers, while achieving equitable results.

If the base saturation of the soil is low, a significant proportion of the fertiliser applied may be lost through nutrient leaching and runoff into waterways.

(14) Liming can reduce stock health problems by increasing the availability of pasture and essential nutrients. Improved availability of the nutrients leads to improved stock health and increased resistance to disease.

(15) Liming assists drainage and cultivation by improving soil texture. Many farmers have reported that liming improves the structure of heavy soils, reduces stickiness and lightens cultivations, making it easier to break down clods and obtain a satisfactory tilth. In the days of horse cultivation, it was said that after very heavy applications of burnt lime, 'four horse land' became 'three horse land' or even less.

(16) Liming improves soil structure by improving soil tilth and crumb formation. Some of this effect may be due to the flocculation of the clay fraction and to the secondary effect of improved soil micro-organism and earthworm activity.

(17) Lime has been shown to increase the activity of soil organisms which are responsible for the breakdown in organic matter to plant available nitrogen. Earthworms are most beneficial to the soil in terms of breakdown of dead plant material, improving soil aeration, increasing water holding capacity and improving water infiltration rates. The latter factor can have a large influence on reducing the risk of erosion and flooding.

(18) Liming 'sweetens' soil. After a good application of lime some weeds become more palatable to stock, encouraging more even grazing. Stock may eat rushes and weeds previously ignored.

1.2 Cautions on liming policies

Excessive application of lime may lead to a reduction in farm production. Applying too much lime can cause the pH to increase above optimum and lead to depressions in pasture growth through a decrease in the availability of trace elements like zinc, boron and manganese. This problem can easily be avoided by regular soil testing.

Negative responses to liming have been found in situations where wide Ca:Mg ratios occur. The soils in the southern South Island seem to present particular risks in this regard. Trials on a Waimumu silt loam in Southland showed liming was harmful where wide Ca:Mg ratios existed, resulting in lowered white clover growth through a deficiency of Mg. This effect is unlikely to be widespread in New Zealand although the incidence of Mg deficiency is becoming more widespread. If economic, the use of Mg fertilisers should be considered in these circumstances.

2.0 Soil Acidity

2.1 What is soil acidity?

Soil acidity refers to the concentration of hydrogen ions (H^+) in the soil, or more correctly the relative concentrations of H^+ and hydroxyl (OH^-) ions. The degree of soil acidity is expressed by means of the pH scale:

$$\mathbf{pH = - Log [H^+].}$$

Soil solutions containing equal concentrations of H^+ and OH^- ions are said to be neutral and have a pH of 7.0. Where the concentration of H^+ ions exceeds that of OH^- the soils are said to be acid and have pH values less than 7.0. Where the concentrations of OH^- ions exceed that of H^+ ions soils are said to be alkaline and have pH values greater than 7.0.

2.2 How do soils become acidic?

Soil acidification is a natural process which can be greatly accelerated by legume based pastoral agriculture, as is very common in New Zealand. A number of processes produce the hydrogen ions that make soils more acidic. Some processes occur naturally, while others result from human activities. A brief outline of factors primarily contributing to soil acidification processes is summarised as follows:

1) Addition of acid compounds to the soil (fertilisers).

2) Generation of acidic compounds within the soil-plant environment.

3) Addition of acid compounds to the soil.

A number of commonly used fertilisers undergo reactions in the soil which tend to increase acidity. These fertilisers include urea, sulphate of ammonia and DAP.

Generation of acidic compounds within the soil - plant environment

The majority of soil acid is generated by the activities of plant roots and soil micro-organisms through:

a) Imbalance in nutrient uptake.

b) Nitrogen fixation and leaching.

(a) Imbalance in nutrient uptake

For a plant to gain nutrients needed for growth and function, the plant roots absorb cations and anions from the atmosphere and from the soil. A cation is any positively charged ion e.g. NH_4^+, Ca_2^+, Mg_2^+, Na^+ or K^+.

The plant is electrically neutral because it has an equal quantity of positive and negative charges. When the plant absorbs a cation in the form of NH_4^+, Ca_2^+, Mg_2^+, Na^+ or K^+,(Fig 1.) the plant then releases into the soil an equal quantity of cations in the form of H^+ ions. (Note: H^+ ions are cations which are acidic.)

This exchange of cations between the soil and plant allows the plant to gain essential nutrients while maintaining the balance of charges within the plant. The soil becomes increasingly acidic due to the increased concentration of H^+ ions released into the soil by the plant. In particular, temperate legumes like clovers, peas, beans and lucerne acidify the soil

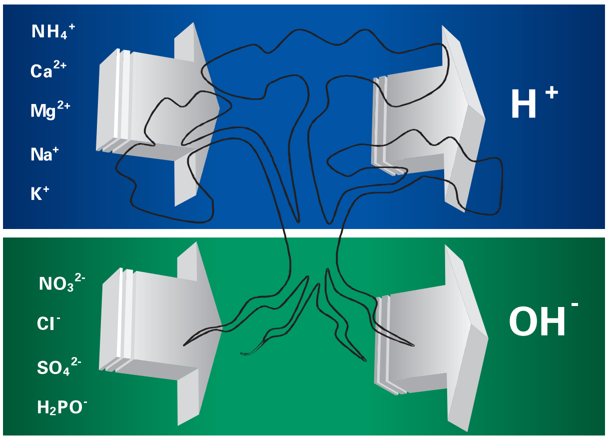


Figure 1. Nutrient Uptake

around their roots when atmospheric nitrogen is being actively fixed in their root nodules.

When plants uptake anions (negatively charged ions) from the soil, OH^- ions (a basic anion) are released into the soil, i.e. when the plant uptakes NO_3^{2-}, Cl^-, SO_4^{2-} or $H_2PO_4^-$ (these anions are relatively non basic) the plant secretes OH^- into the soil. This causes the soil to become more alkaline or basic.

Theoretically the alkalising process should neutralise the acidifying process in the soil. However, the plant uptakes more cations than anions, hence more H^+ ions (acid) than OH^- ions (alkali) are secreted into the soil. Therefore the soil becomes acidified.

b) Nitrogen fixation and leaching

Most of the nitrogen fixed by legumes and absorbed by the plant is consumed by grazing stock, and is then excreted as urine and dung. Most of the nitrogen in urine is present as urea. Hydrolysis of urea to ammonia and ammonium ions occurs rapidly in the soil followed by nitrification of a variable proportion of the ammonium to produce nitrate (NO_3^-). The chemical reactions occurring in this process produce H^+ (acidic cation). See Fig 2.

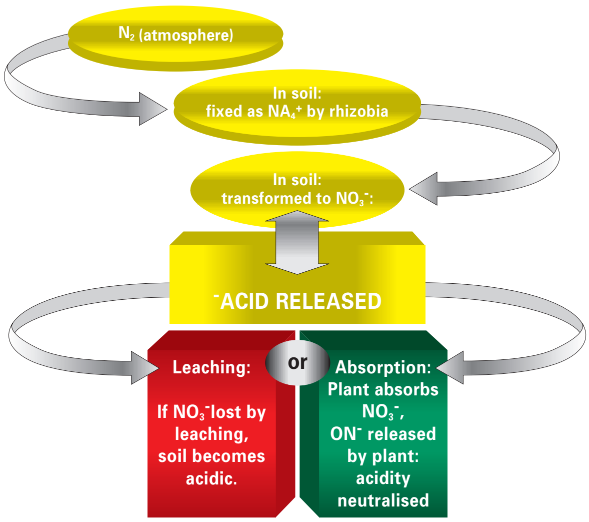


Figure 2. Nitrogen fixation, leaching and acidification.

If all the nitrogen entering the soil was taken up by plants there would be no net acidification or alkalisation. However, if instead of being taken up by plants the nitrate is leached from the soil, soil acidification occurs.

Acidification occurs because for the nitrate anion (negatively charged ion) to leach from the soil, it must be accompanied by a cation (positively charged ion). The cation leached along with the nitrate to balance its charge is mainly calcium or magnesium, while the H^+ ion remains in the topsoil which is thereby acidified.

2.3 Why are we concerned about soil pH?

When soils become acidic there are several important changes taking place in the soil which are detrimental to achieving or maintaining high producing farmland.

Increased acidity leads to the following changes within the soil:

1) The principal effect of soil acidity is to influence the availability of plant nutrients. Many important plant nutrients, particularly phosphorus and molybdenum, are less soluble and therefore unavailable to plants in acid soils.

2) Elements such as aluminium and manganese become more soluble in acid soils and can become toxic to plant growth.

3) A low pH may indicate a low level of calcium and magnesium.

4) Many soil organisms (e.g. worms and micro-organisms) suffer in acid soil.

5) Changes in botanical composition of pastures to lower fertility species often lead to a decrease in palatability of pasture.

These problems can be overcome by the addition of lime. It is stated in point number 1) above, that at low pH, phosphorus and molybdenum become less soluble and therefore less available. The implication is that if the pH is increased (by liming) then phosphorus and molybdenum will become more available. It should be noted that liming would only increase the amount of plant available molybdenum on soils which have a reserve of molybdenum. There are some soils in New Zealand (e.g. some highly weathered "gumland" soils of Northland and deep acid peats in the Waikato) that have no reserve molybdenum. In such cases molybdenum must be applied as a fertiliser.

Structure of soils may deteriorate leading to a decrease in the soil moisture holding and rewetting capabilities. The soil becomes more vulnerable to the detrimental effects of dry weather.

2.4 Subsoil acidification "could cost the earth"

An issue of particular concern for New Zealand hill country farmers is subsoil acidification. Subsoil acidification is an ongoing process. As previously noted, the result of farming ryegrass-clover pastures is an increase in acidification, which can result in aluminium toxicity. This interferes with root production and plant growth.

If acidity builds up in the lower root zone, productivity and drought tolerance can drop slowly and steadily. Sub-soil acidity is a major problem in Australia, across millions of hectares in Victoria, New South Wales, South Australia and Western Australia. This is made worse by the fact that lime is not commonly used in Australian agriculture. Although Australian soils have less capacity to buffer acidity than New Zealand's geologically younger soils, there is a risk of long term sub-soil acidity here.

Dr Mike Hedley, acting director of Massey University's fertiliser and lime research centre advises that scientists can't as yet predict how long it will take acidity to reach critical levels in the sub-soil. "But we know we are producing acidity, and there will be a time when our hill country soils are too acidic to support improved pastures" he says. "The problem foreseen by researchers is long term and will only occur when lime is not used regularly". The answer is liming to neutralise the acid, and increase pH.

A serious problem for the hill country farmer is that spreading vehicles can not be taken up into the steeper hills. The only way to spread lime is by aircraft, which may not be economic for many farmers. Research in the King Country (O'Connor et. al. 1981) has indicated that low rates of lime in hill country may be very beneficial.

When the soil can't be ploughed, as is the case for many hill country farmers, sub-soil acidification, when left too late, will be very difficult and expensive to remedy. New Zealand hill country farmers will have to lime their land, or their grandchildren will face a soil acidity problem which could eventually cut production and "cost the earth" to cure.

2.5 Indications of soil acidity

Many farmers will agree that it is a very valuable skill to be able to recognise visual indicators of lime deficiencies. Presented below is a list of some of the observational signs of lime requirement, which may initially alert you to obvious lime deficiencies. However, soil tests are a necessary tool in determining lime requirements. These observational signs are not a substitute for soil tests.

Observational signs of lime requirement

- The presence of flat weeds (dandelions and plantain), moss, chickweed and/or yarrow.
- Poor clover nodulation leading to poor clover growth. This can easily be observed by a high presence of variable sized clovers or an overall general absence of clover. Absence of clover is often a sign of lime deficiency which is usually associated with a shortage of phosphate. On some soils, lack of clovers may be due to potassium deficiency.
- Bare patches of plant growth on the soil surface.
- Poor worm life.
- Shallow rooting of pasture plants.
- Thatching at and near the soil surface.
- On grassland a shortage of lime often leads to a matted and peaty layer of unrotted grass debris on the surface of the soil.

Arable crops such as sugar beet and barley are very sensitive to soil acidity. Often they give the first indication that land is becoming acid by growing poorly or by completely failing to grow in patches. Other crops that are affected by acid soils, although less susceptible are beans, peas, turnips, swedes and wheat.

Section 6.8.17 gives observational signs of specific nutrient deficiencies in various pasture plants and crops. Nutrient deficiencies can be closely related to the way in which soil acidity affects the availability of plant nutrients, and thereby gives signs of soil acidification.

The following quote is an old saying, which originated in an era before farmers had ever even heard of soil pH. It shows some obvious understanding and appreciation of lime requirements. The quote refers to the appearance of a paddock after it has been grazed.

"Where there's no grass, fertilise. Where there's tufts of grass, lime".

The theory being that to grow grass you need fertiliser but where there is rank grass, the stock find it too unpalatable and leave it.

3.0 Overcoming Soil Acidity

Soil acidity may be economically and effectively overcome by the addition of ground limestone.

3.1 How does lime work to overcome soil acidity?

Ground limestone consists of calcium carbonate and variable proportions of sand, silt or clay. When calcium carbonate is in contact with a slightly acid soil, the calcium carbonate dissolves gradually in the soil moisture and reduces acidity.

Lime neutralises the soil in two ways:

(1) The acidic hydrogen ions (H^+) react with the $CaCO_3$ to produce carbonic acid and calcium ions (Ca_2^+). Carbonic acid is unstable and breaks down to form water and carbon dioxide.

(2) The calcium ions (Ca_2^+) displace the H^+ ions in the soil.

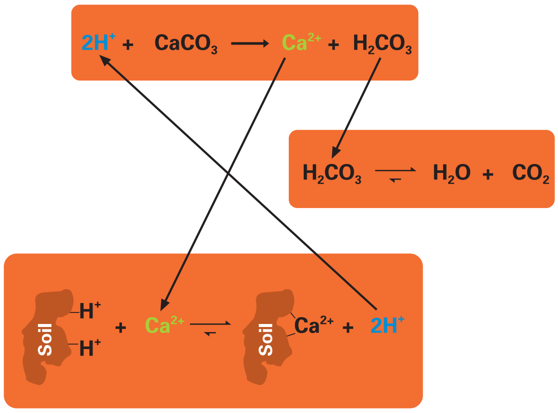


Figure 3. How lime neutralises soil acidity

3.2 Liming Materials

The most cost-effective method of raising the pH of your soil is through the application of agricultural lime (calcium carbonate). Other materials are listed below and their respective liming power compared to calcium carbonate is given as a neutralising "value".

Table 1. The Neutralising Values for Various Liming Materials Compared to the Neutralising Value of Calcium Carbonate.

Liming material	Neutralising value %
Calcium carbonate $CaCO_3$	100
Dolomite Lime $CaMg(CO_3)_2$	95-108
Hydrated Lime $Ca(OH)_2$	120-135
Basic Slag (no P in NZ slag)	50-70
Baked Sea Shells	80-90
Marl Clay + $CaCO_3$	50-90
Burnt Lime (Quicklime) CaO	150-175
Gypsum $CaSO_4$	None

4.0 Lime Quality – Get the best value for your money.

4.1 Calcium carbonate content

The most important component in agricultural lime is the calcium carbonate content. The carbonate reacts with the acids in the soil and thereby increases the soil pH. The calcium carbonate of Northland limestone ranges from 60-85%. In certain parts of New Zealand the calcium carbonate content of lime may range up to 99%.

In the past there have been regulations which controlled the quality of agricultural lime through transport subsidies. In Northland, approved limeworks were only able to sell lime with a minimum of 65% calcium carbonate content. There were some exceptions to this, which allowed some limeworks to sell lime with a minimum of 60% calcium carbonate. Now that the transport subsidies have been removed, there are no regulations controlling the quality of agricultural lime. It is therefore highly advisable for farmers to see a recent $CaCO_3$ analysis of the lime before purchase.

TRACTOR SPREADER

4.2 Fineness of grinding

Another important factor when considering lime quality is the fineness of grinding or surface area of the lime particle. The surface area increases in almost direct proportion to the fineness of grinding. At any given constant weight, if the particle size is halved the surface area is doubled. Other factors being constant, fineness of grinding has a very large bearing on the rapidity with which liming affects plant growth and soil pH.

Agricultural limestone usually has a wide range of particle sizes. This is a desirable feature unless too large a proportion of the particles is so coarse that under most conditions little will dissolve for many years.

The fineness of lime is measured by passing it through a series of standard sieves. The previous M.A.F. regulations controlling the fineness of grinding of agricultural lime specified the following:

- At least 95% of the ground limestone to pass through a 2.0mm sieve.
- At least 50% of the ground limestone to pass through a 0.5mm sieve.

It is important that such standards continue to be adhered to.

4.3 Transport and spreading costs

When considering lime sources it is advisable to take into account not only the grade of limestone, but also the costs of transport and spreading.

A situation may arise where the local limestone is of a low grade. A higher grade product may be available from another lime source a greater distance from the spreading site. The cost of carting the higher-grade product the extra distance may make the higher grade product less economic. It may be more economic to purchase the lower grade product at a higher quantity.

In other situations it may be more economic to purchase a lower quantity of the higher grade product.

The following scenarios demonstrate the importance of taking into account all the economic costs and benefits of employing a particular lime source. Two lime sources are available:

Table 2. Comparing Two Lime Sources

		Lime works (X)	**Lime works (Y)**
A	$CaCO_3$	75%	60%
B	Lime price $/tonne	14	10
C	$CaCO_3$ required (tonnes)	100	100
D	Tonnes product required (C)	133	167
E	Lime per truck load (tonnes)	20	20
F	Number of loads (DIE)	6.65	8.35
G	Cartage distance (round trip)	70km	40km
H	Cost cartage $/km	2.5	2.5
I	Air spreading costs $/tonne	32	32
J	Ground spreading costs $/tonne	8	8

Example 1: A farmer requires a volume of lime with an equivalent of 100 tonnes of calcium carbonate to be transported to his farm and spread on his land by a ground spreader.

Table 3. Calculations for Example 1

	Lime works (X)		
Cost of Lime:	(D x B)	=(133 x 14)	1,862
Cost of Cartage:	(F x G x H)	=(6.65 x 70 x 2.50)	1,164
Cost of Spreading:	(D x I)	=(133 x 8)	1,064
		Total	**$4,090**
	Lime works (Y)		
Cost of Lime:	(D x B)	=(167 x 10)	1,670
Cost of Cartage:	(F x G x H)	=(8.35 x 40 x 2.50)	835
Cost of Spreading:	(D x I)	=(167 x 8)	1,336
		Total	**$3,841**

Note: Input parameters for Example 1 were obtained from Table 2.

In this scenario it is clear that lime works (Y) proves to be the cheaper option, even though its purity is lower and a greater volume of lime is required. Cartage costs are significantly reduced by the shorter distance of transport to the farm. Applying a lower grade product at a higher quantity becomes the more economic option in this case.

Example 2: A hill country farmer requires a volume of lime with an equivalent of 100 tonnes of calcium carbonate to be transported to an airstrip bin and spread onto his farm by a spreading plane.

Table 4. Calculations for Example 2

	Lime works (X)		
Cost of Lime:	(D x B)	=(133 x 14)	1,862
Cost of Cartage:	(F x G x H)	=(6.65 x 70 x 2.50)	1,164
Cost of Spreading:	(D x I)	=(133 x 32)	4,256
			Total $7,282
	Lime works (Y)		
Cost of Lime:	(D x B)	=(167 x 10)	1,670
Cost of Cartage:	(F x G x H)	=(8.35 x 40 x 2.50)	835
Cost of Spreading:	(D x I)	=(167 x 32)	5,344
			Total $7,849

Note: Input parameters for Example 2 were obtained from Table 2.

In this scenario lime works (X) proves to be the cheaper option as its higher quality limestone means there is less lime needing to be applied and so total on-ground costs are lower.

5.0 Chemical Composition of Lime

Major Constituents

New Zealand limestone can contain up to 99% calcium carbonate. The most important constituent of lime is the carbonate anion. The carbonate anion reduces the soil acidity producing CO_2 and water (see Figure 3). The other major component is calcium. Calcium is an essential plant and animal nutrient. Its presence is essential to ensure the absorption and movement of growth elements such as phosphorus, magnesium and nitrogen.

The other major component of limestone is silica. This is a relatively inert material and has very little agricultural value.

Minor Constituents

Limestone also contains trace elements in varying quantities and proportions.

Sixteen samples were taken from limestones in Northland to reveal the following average chemical compositions of trace elements.

Table 5. Average Sample Composition for Trace Elements

Trace Element	Average Sample Composition
Iron (Fe)	0.1-1.1%
Magnesium (Mg)	0.1-0.15%
Copper (Cu)	14-27ppm
Cobalt (Co)	10-14ppm
Manganese (Mn)	100-600ppm
Molybdenum (Mb)	0.2-0.8ppm
Zinc (Zn)	22-39ppm
Cadmium (Cd)	3-5ppm

6.0 How Liming Improves Farm Production

6.1 Increased pasture production

The objective of lime application in agriculture is to increase pasture production.

By raising the soil pH, lime affects the availability of major and trace elements including nitrogen, calcium, magnesium, molybdenum, manganese, boron, zinc and aluminium. Under certain conditions lime has a ‘phosphate sparing effect’. Liming also improves soil physical structure and moisture retention. Lime has a beneficial effect on some soil fauna, especially earthworms and nitrogen fixing bacteria. All these factors work together and contribute to significant increases in pasture production. The improvements in pasture production lead to increases in animal production, measured in live weight, wool weight and milksolids. Overall the effect is to increase farm profitability.

Over the past 30 years a lot of scientific research has been undertaken concerned with pasture responses to liming. Field trials conducted by M.A.F., D.S.I.R. and the universities (Massey and Lincoln) have shown that farm pasture production can be significantly increased through liming. Some of the more recent trials in Northland have included the Kamo trials, Waiotira-Lovegrove trials, the Waiotira-Gunson trials and the Ruawai trials. These trials were conducted on typical unimproved or improved hill country pasture. The most noteworthy findings of these trials are summarised below, giving some indication of how liming can significantly increase pasture production.

Kamo:

The Kamo trials were established in June 1990 on an undeveloped site on the Kamo research area. These trials exhibited an average production increase of 31% through liming. The Kamo site was a typical “development” situation with low pH (4.9) and indicating a very marked improvement to raising soil pH to optimum levels.

Waiotira - Gunson:

This trial was established in July 1991 on a farm near Waiotira, the property of P & B Gunson. The Gunson trials on Waiotira clay showed an increase in pasture production of 18%. The site had a starting pH of 5.6, which is considerably higher than the Kamo (4.9) or Lovegrove (5.3) trials. This site was typical of run down pasture, which had received little or no fertiliser for 8 - 10 years. Researchers suggest that a major contribution of the lime response was due to nitrogen release as a result of applying lime, which resulted in a marked improvement in ryegrass content.

Waiotira - Lovegrove:

The Lovegrove trials were established in June 1993 on a farm near Waiotira, property of M. & A. Lovegrove. The Lovegrove site was typical of a lot of Northland rolling hill country with clay soils. Lime responses of 15% production increases were observed in the second year of the trials. The third year had a 6% increase in production and over the next few years maintained a similar advantage. The first year’s production was limited by the fact that it was an extremely dry year and that liming normally requires a certain amount of time to take effect. The researchers suggest that the improvements in production may be largely due to liming alleviating aluminium toxicity problems. With a pH of 5.3 the soil aluminium levels at 2.7ppm (range 2.35-3.22ppm) were high enough to exert a depressive effect on plant growth.

Ruawai - Tony Oud:
A trial was laid down on the property of Tony Oud, Robertson Road, on 10 December 1996. The soil type was Kaipara clay and soil tests initially revealed pH 5.9 and Olsen P 16. The study focussed on the effects of lime and phosphate on pasture growth. By the second year of the trial some important interactions were apparent between lime and phosphate. When lime alone was applied at 5 tonne/ha in year 1, an increase in kgDM/ha of 20% was observed. The increase in dry matter production was attributed to the lime rendering the phosphate already present in the soil, more available to plants. This effect is sometimes referred to as a 'phosphate sparing effect'. The lime response was equivalent to that obtained from 80-100kg P/ha (890-1110kg Superphosphate/ha) without lime.

Results obtained in this trial will be applicable to Kaipara clay soils and probably other estuarine clays in Northland. These results are supported by trials carried out in 1991 on the property of R Kidd. The site originally had a pH of 5.5 and an Olsen P of 15 and showed a 15% increase in dry matter in response to phosphate alone, a 16% response to lime alone and a 25% response to P and lime together. Obviously the combination of lime and Superphosphate is the ideal.

6.2 Expected pasture responses to liming

Lime trials carried out in Northland have indicated that knowing the initial soil pH, responses to lime may be predicted with reasonable accuracy although these will vary to some degree between sites, depending on factors including soil type, climate and the quantity of lime applied.

Figure 4(a) is based on information gained in the Lovegrove trials. A positive response to lime application was obtained across the pH range. Indications from this trial were that the quicker the pH could be raised to an optimum level (pH 6.0-6.2) the better it was in terms of pasture response.

Figure 4(a) Pasture Responses to Lime Across the pH Range 5.2-6.2 (Lovegrove trial)

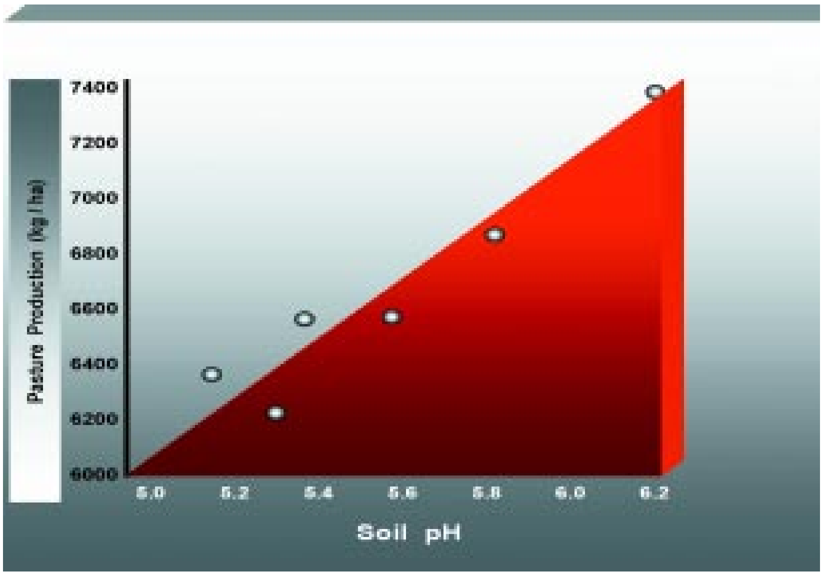


Figure 4(b) Relationship Between Soil pH and Average Annual Pasture Response (%) to Lime at 3 Application Rates

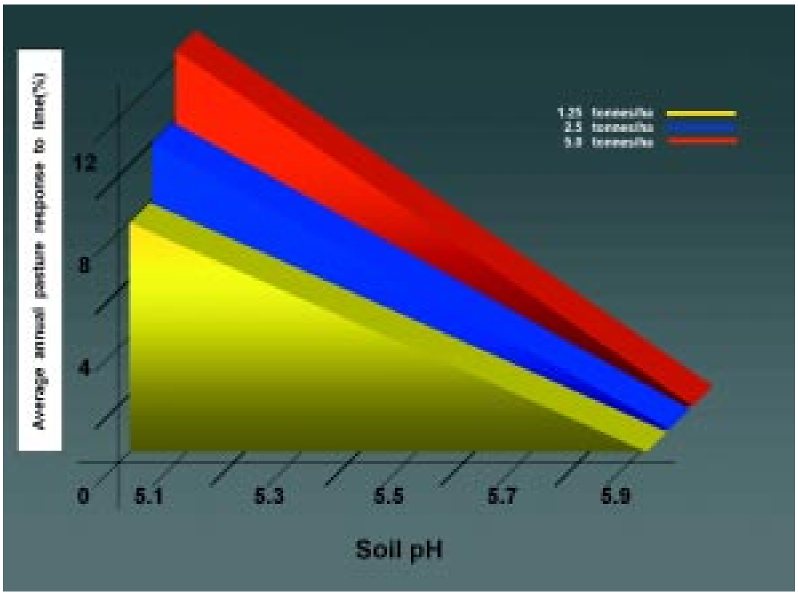


Figure 4(b) gives responses to lime that can be expected based on the initial soil pH and the quantity of lime applied. For example, starting with a soil pH of 5.0, a 10% increase in pasture production can be expected with an application of 2.5 tonnes/ha.

Responses to lime are generally measured in dry matter production by researchers. However, improvements in stock production, animal health and pasture compositions are just as relevant. Several authors have noted that in situations where both animal and pasture measurements were made, animal production measurements (e.g. wool production, live weight gains, or milksolid production) offer the best and most consistent indication of lime responses as the animal is able to integrate the effects over time. In the absence of animal production measurements, pasture production is a good measure of the effects of lime.

6.3 Liming to improve soil properties

6.3.1 Soil moisture

Microbial activity is low and nutrient availability to plants is limited when a soil is under moisture stress. The evidence from many field trials has shown that lime addition can result in increased soil moisture levels, particularly after rainfall in March-April. Such a moisture advantage at this time of the year will encourage and support active plant growth. This may allow persistence of desirable species and promote earlier autumn germination of seeds.

In a study of the effect of lime on North Island hill country Zhou Jiayou (1993) found that liming significantly increased the soil pH ranging from 0.24 to 0.3 units/2000kg lime applied, and the soil potential mineralization nitrogen increased by 93.8%. Liming increased the soil moisture over dry spring/summer by values ranging from 11.2% to 26.3%.

The Whatawhata Hill Research Centre is located on hilly and steep slopes with pH 4.8 to 5.5 and a mean annual rainfall of 600mm. The application of 3 tonnes lime/ha consistently increased soil moisture and with outstanding results. Within 2 years, herbage yield in one summer and autumn were trebled. In addition, the proportion of white clover in the sward doubled.

Lime may affect soil moisture in two ways, either directly and rapidly, or indirectly and gradually. In the experiment at Whatawhata, lime acted relatively rapidly. One month after application and when approximately 200mm of rain had fallen, liming greatly increased the speed with which droplets entered the soil.

Gradual effects may be caused by stimulation of earthworm activity and micro-organisms. This results in the disappearance of the water repellent turf mat and the formation of water conducting channels.

It is not known if this effect on soil moisture is widespread because in several other trials in the North Island hill country, liming increased herbage yields but not soil moisture. Increased soil moisture content appears to accompany a lime stimulated increase in white clover production. In general terms a soil moisture effect must be considered a possibility.

6.3.2 Liming to improve soil structure

It is widely accepted by farmers that liming improves the structure of heavy soils, reduces stickiness, lightens cultivation and makes it easier to break down clods and obtain a satisfactory tilth. In the days of horse cultivation it was often said that after very heavy applications of burnt lime 'four-horse land' became 'three-horse land' or even less.

The addition of lime increases the population of the bacteria responsible for breaking down organic matter. The decomposition of organic matter is believed to assist soil crumb formation, possibly through the formation of gum-like substances, which act as cements, or through soluble humic materials which coat the soil crumbs and bind them on drying.

Another indirect benefit on soil structure, is a significant increase in earthworm numbers and activity.

6.3.3 Liming to increase earthworm activity and numbers

Casting earthworms are beneficial for maintaining healthy soils and for maximising production of crop systems and pasture. Some important earthworm species respond to liming.

Casting earthworms depend on a constant supply of calcium in greater amounts than are naturally present in New Zealand soils. Calcium supplied through liming stimulates earthworm production and activity. In trials in the South Island numbers have increased by 50% in response to 2.5 tonnes/ha of lime, and 90% in response to 5 tonnes/ha. Low populations are often associated with low calcium levels, and a soil test calcium level of at least 7 is required for useful earthworm activity.

Signs of lack of worms

Pastures lacking in earthworms can be recognised by their lack of sustained vigour and absence of surface worm casts. These pastures have a harsh unthrifty appearance. Dung and dead plant material is observed over a compact, structureless and relatively dry soil.

Beneficial effects of earthworms

A 72% increase in spring pasture production was measured in Hindon, Otago, 5 years after earthworms were introduced. Dry matter (DM) increases from 28 -111% have been measured in pot trials as a result of earthworm activity.

The obvious changes resulting from earthworm activity are the incorporation of organic matter from the soil surface, and the strikingly improved open friable structure of the soil.

Under good pasture, the weight of casting earthworms may exceed one tonne per hectare, and while moisture and food are in good supply they may daily ingest 3-4 times their own weight in soil, dung, litter and decaying roots. During the digestion of these materials, the availability of nitrogen and phosphate is increased. This increases the rate of nutrient re-cycling back to the pasture.
Perhaps the most important function of earthworms is their effect on infiltration of rainwater. Worms affect the pore size distribution in the soil, improving drainage. The mucous secretions they release reduce the hydrophobic nature of the soil particles. Water penetration is also increased because there is a reduction of the litter layer due to earthworm activity.

LIME BULK STORE

Earthworms have doubled or even trebled the infiltration rate of rainwater. Increased infiltration reduces runoff, erosion and flooding. Improved crumb structure lessens the risk of wind erosion.
The presence of earthworms can, therefore, greatly increase pasture growth and reduce the chance of erosion and loss of nutrients in runoff. In some trials performed by M.A.F., the infiltration rate doubled from 12.5mm to 25mm/hr, moisture holding capacity increased 17% and available moisture in the top 30cm increased by 17.5mm in the soils tested.

Important species of worms
There are over 190 earthworm species in New Zealand, but only a few introduced species are regarded as beneficial.

Aporrectodea caliginosa is the most widespread. It feeds on dung but is mainly active from just below the surface to 6cm depth. It produces casts but seldom brings them to the surface. Most importantly, it prevents the formation of turf mats and assists in their destruction. Other introduced species that seem to have similar effects include *A. tubercuiata, A. rosea, A. Chiorotica, A. trapezoides and A. Longa.*

Lubicus rubellus feeds on dung, plant litter and decaying roots to a depth of about 3cm below the soil surface. This species may contribute significantly to the efficient cycling of nutrients, particularly nitrogen and phosphorus. Although *Lubicus* produces surface casts it does not prevent the formation of turf mat.

All the above species are good colonisers and are common in soils with pH 5.2-5.4. They have been observed to respond dramatically in vigour and numbers to liming up to pH 6.0-6.2. *Aporrectodea longa* may be even more responsive to liming than *Lubicus rubellus and A. caliginosa.*

6.4 Liming supplies calcium to the soil
Calcium carbonate has a dual function in the soil:

- Calcium is an essential plant and animal nutrient.

- Carbonate is the dominant base, which reacts chemically with acids, keeping soils neutral in reaction.

Calcium in the soil is held mainly in the clay and organic matter such that it can be replaced by, or exchanged with, other plant nutrients.

In soils saturated with calcium, Ca_2^+ ions neutralise most of the negative charges on the colloids of the clay and organic matter fractions. If calcium ions lost by leaching are not replaced, positively charged hydrogen ions (which are responsible for acidity) take their place and the soil becomes acidic.

Various processes such as leaching, crop uptake and reaction with fertilisers result in loss of lime from the soil. (See section 8.0)

When lime dressings are added to the soil, any deficit of exchangeable calcium is made up first, and any excess of lime remains as free calcium carbonate in the soil. Soils have no mechanism for conserving (i.e. fixing) surplus calcium in non-exchangeable but potentially useful forms. Once the free calcium carbonate has been exhausted, lime losses will deplete the exchangeable calcium, and the soil will then become progressively more acid. Unless the decrease in soil pH is corrected by the addition of lime, yield reductions and crop failures can be expected. So long as reserves of free calcium or magnesium carbonate are available, lime losses will be balanced and the soil will remain neutral.

6.5 The effect of liming in reducing toxicities

6.5.1 Aluminium toxicity

At low soil pH ($pH < 5.5$) aluminium(Al) can be present in the soil in toxic concentrations. Liming to increase soil pH above 5.5 reduces available soil Al and alleviates aluminium toxicity. Al toxicity restricts root growth and hence the ability of legumes, grasses and other plants to take up nutrients. Al toxicity increases water stress during dry periods as poor root growth limits the ability of plants to take up water. It also inhibits nodulation of legumes.

Aluminium toxicity occurs primarily in mineral soils of temperate climates. It is particularly likely to be a production-limiting factor on North Island hill country soils and on upland soils in the South Island.

Aluminium problems seldom appear in organic soils as these soils have low Al concentrations. Plants tolerate acidic organic soils better than acidic mineral soils, primarily owing to their low aluminium levels. In peaty loams with mineral matter greater than 5-10%, aluminium toxicity may be significant.

Aluminium toxicity is likely to affect production of lucerne as it is particularly sensitive to Al toxicity.

6.5.2 Manganese toxicity

Manganese (Mn) toxicity in pasture is relatively rare in New Zealand. The availability of soil Mn varies greatly with pH. In acid soils and particularly under waterlogged conditions, Mn can reach toxic levels.

High Mn levels in pastures have been found to have a detrimental effect on animal performance, particularly in sheep. Levels of 400-700mg Mn/kg DM when fed to lambs caused a significant reduction in liveweight gain compared to lambs fed normal pasture.

Although herbage Mn levels in excess of 200 mg/kg may not be toxic to the animal, it is possible that they affect animal health by competing with copper (Cu) for biochemical sites in the liver. Results from a survey of sheep farms in the Manawatu indicate that Cu deficient levels in liver were associated with a high concentration of manganese in mixed pasture, whereas adequate Cu status was invariably associated with much lower pasture manganese concentrations.

6.5.3 Toxic metals

Liming of areas polluted by toxic metals reduces the negative effects associated with toxic metal contamination. Soils with high levels of toxic metals are occasionally encountered in the neighbourhood of metaliferous mines, on the flood plains of some rivers, and in fields treated with large amounts of sewage sludge contaminated with industrial waste. Maintaining the soil pH at 7 or above minimises the effects of toxic metals, although where metal concentrations are very high, little can be done to the soil to overcome the problem.

6.6 Liming to improve pasture utilisation

Limed pastures tend to be more palatable to stock, resulting in better pasture utilisation, and more even grazing.

This was observed in a lamb growth trial on King Country ash soils conducted between 1975 and 1982. Live weight gains and wool weight gains were recorded for most years and sites (70-80% positive response). Lambs were observed to have a grazing preference for the limed pastures. Researchers suggested that the reason for the improved palatability in the lime trial was a possible improvement in botanical composition.

6.6.1 Changes in botanical composition of pastures

Liming generally encourages more productive pasture species (legumes and rye grasses) at the expense of low fertility species such as brown top. Liming can increase the growth of legume and/or high fertility grasses on soils with initially low pH (pH<5.5), where aluminium or manganese toxicity is limiting growth. Applying lime to soils with a pH>5.5 often increases the rye grass component by releasing mineral N. A number of other mechanisms such as increasing P and Mo availability and improved moisture status may be contributing factors.

6.6.2 Grazing preference

Many farmers have reported that their cows graze more evenly and are often quieter and happier when grazing limed paddocks. While it is difficult if not impossible to measure such observations, considerable value is placed on them.

In some cases where the botanical composition of pasture was already very healthy prior to liming, farmers reported that their livestock preferred limed pastures and showed improved thrift. As the botanical composition of the pasture did not seem to change, the preference of the stock for limed pastures must have been due to some other factor.

In 1975 it was decided to test these claims on the yellow-brown loams of the King Country by conducting regionally dispersed farmlet scale grazing experiments using ewe lambs as the test animals. (Toxopeus, 1989)

A "grazing preference" for limed pastures was observed on 4 out of the 6 sites around Te Kuiti and on one near Taupo, either in the first season or later, even after the field was returned to common farming. The reasons for grazing preference are still not clear.

Trial work done at Ruakura in the 1980's indicated that there was no difference between lime treated and untreated pasture in terms of its feeding value but animals still preferred the limed pastures.

6.7 Lime and fertilisers

Lime, locally produced at low cost, maximises the return from money spent on fertilisers by reducing soil acidity and increasing uptake of the primary nutrients. This is one of the most important benefits of liming.

Lime is not a substitute for fertiliser but there are circumstances when low pH may prevent the response to applied nutrients. For example, on acid soils, with acid sensitive species, pasture may not respond to phosphorus until aluminium toxicity is removed.

Liming and fertilisation usually go together as complementary practices. Ideally, this involves good crop rotations with well-fertilised restorative as well as depletive crops being used to maintain organic matter levels. As the Chinese saying goes "Too much lime and no manure makes the father rich and the son poor".

6.8 The effects of liming on the availability of plant nutrients

6.8.1 Essential elements in plants and animals

Plant and animal tissue consists of carbon (C), hydrogen (H), oxygen (O) and about 15 mineral elements. The first three (C,H,O), together with nitrogen (N), phosphorus (P) and sulphur (S), make up the living matter in plants and animals, while calcium (Ca) and (P) form animal skeletons. The remaining elements are generally required by the various enzyme systems of plants and animals, or nerve activity in animals.
Growth and yield of crops are determined to a large extent by the nutrient element that is present in the smallest quantity to the plants' requirements.

Table 6. Major and Trace Elements

Major elements	Trace elements
Nitrogen (N)	Boron (B)
Phosphorus (P)	Iron (Fe)
Potassium (K)	Manganese (Mn)
Sulphur (S)	Copper (Cu)
Calcium (Ca)	Zinc (Zn)
Magnesium (Mg)	Molybdenum (Mo)
*Sodium (Na)	Chlorine (Cl)
*Cobalt (Co)	*Selenium (Se)

* There is no known function for Na, Co or Se in plants, although Co is required by N-fixing rhizobia in clover nodules. There is no known function for B in animals.

6.8.2 Trace elements

Trace elements are found in animals and plants in only minute quantities but are required for essential biological functions.

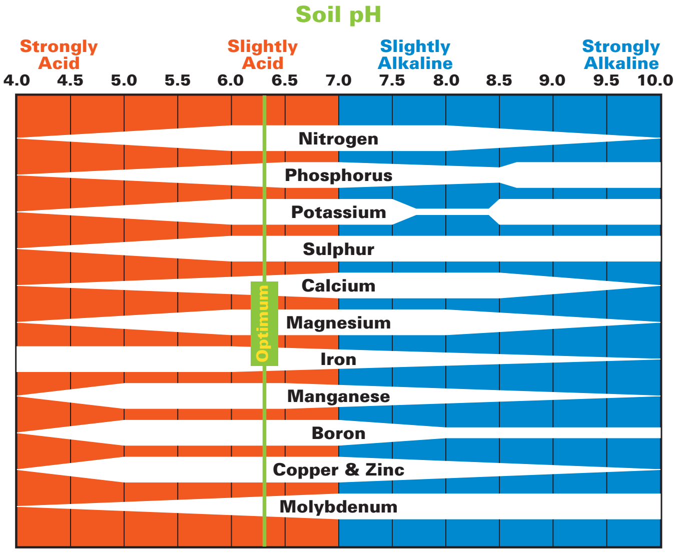
A knowledge of the trace element status of a property is essential when farming for high production, but in comparison with major production limiting factors (i.e. the role of dry matter production) the role of trace elements is of lesser importance.

Trace element deficiencies are often induced by insufficient total dry matter intake (starvation) and parasitism problems.

6.8.3 Nutrient availability as affected by pH of the soil

If soil is too acid or too alkaline then many of the existing or added soil nutrients are converted to forms that are unavailable to plant and animal life.

Figure 5. Influence of pH on Nutrient Availability



The diagram in Figure 5. shows the influence of pH on nutrient availability in determined average conditions.

The elements which are of greatest importance in plant nutrition are represented by horizontal bars. The breadth of a bar shows the relative availability of the nutrient concerned at a definite pH. The optimum pH for maximum availability of important nutrients is shown by a vertical line through the diagram.

The major nutrients and molybdenum are most available in near neutral soil. The other trace elements are more available in more acidic soil. Note that pH in the range of 6.0-7.0 is a good average level for all nutrients. This is also the best pH range for most crops.

6.8.4 Nitrogen

Liming increases the rate of break down of soil organic matter by increasing microbial activity, thus releasing otherwise unavailable nitrogen N. In a field trial in Taranaki 5 tonnes/ha of lime released 25kg N/ha annually.

In trials in Hawkes Bay it was found that the net N mineralised per annum over 2 years was obtained by multiplying the tonnes/ha lime applied by 3.3.

Nitrogen availability can also be increased by lime increasing clover growth and a subsequent transfer of nitrogen from clover to grass.

Nitrogen from organic matter, either from applied organic manures or from plant residues, is converted into ammonium and nitrate forms which are available to plants by the activity of micro-organisms, principally bacteria.

Ammonium producing organisms are not greatly affected by soil acidity. The bacteria responsible for the conversion of ammonium to nitrate (which is the most readily available form of nitrogen) are inhibited by acid soils. The application of lime raises soil pH causing soil conditions to be more favourable for the bacteria responsible for the conversion of ammonium to nitrate. In this way the addition of lime stimulates nitrification with the production of readily available nitrate N.

"TOPP" LIME SCREENING UNIT

The process of fixation of atmospheric N by bacteria in the roots of leguminous plants is greatly retarded in soils with either very high or very low pH. A pH around 6.0 is generally considered most favourable for N fixation, but a few leguminous plants will grow and fix N satisfactorily under much more extreme conditions. The most favourable pH for nitrification is between 6 and 8.

6.8.5 Phosphorus

Phosphate fertiliser is applied regularly to most farmland in New Zealand and constitutes a major input cost in most agricultural systems. There are many contradictory reports in the literature on the effects of liming on soil phosphorus (P) availability and the uptake of P by plants. Many of these apparent inconsistencies can be explained by differences between studies in the initial and final soil pH, and whether P availability was assessed by plant uptake or a variety of chemical extractants. There are a number of factors which are considered with some certainty and these are summarised as follows.

In acid soils there are often spectacular interactions between lime and phosphate. In such situations there are often high concentrations of soluble aluminium (Al) in the soil and also in plant roots. At low pH values, on soils high in aluminium or iron, phosphates are rendered less available because of their reaction with these compounds. In these circumstances plants often appear phosphate deficient with narrow dark green leaves and purpling of the stems. The addition of lime to these soils will deactivate the iron or aluminium, thus increasing the level of plant available phosphorus.

With lime responsive soils, lime often slightly increases phosphate uptake in individual plant species. This effect can be masked by changes in the proportion of clovers. Plants often appear P deficient and both P and lime are required to achieve maximum yields.

The ability of lime to increase the availability of phosphorus to plants is sometimes referred to as a "phosphate sparing" effect. This phosphate sparing effect has not been found to occur in all areas and is difficult to predict from year to year. It is particularly notable on sedimentary soils with a low pH (pH<5.5) on the east coast of New Zealand. In a recent trial at Ruawai on Kaipara clay soil (Tony Oud trials), the initial soil test was pH 5.9 and Olsen P 16. In the second year the results indicated a strong phosphate sparing effect. When lime alone was applied at 5t/ha (in year 1) an increase in kgDM/ha of 20% was observed. The increase in dry matter production was attributed to the lime rendering the phosphate already present in the soil more biologically available to plants.

Results obtained in this trial will be applicable to all Kaipara clay soils and probably other estuarine clays in Northland. These results are supported by trials carried out in 1991 on the property of R Kidd. The site originally had a pH of 5.5 and an Olsen P of 15 and showed a 15% increase in dry matter production in response to phosphate alone, a 16% response to lime alone and a 25% response to P and lime together.

In general the most favourable pH for phosphorus availability is around 6.0. Above pH 7, phosphate availability decreases as insoluble tri-calcium phosphate is formed.

6.8.6 Manganese

Manganese (Mn) occurs in several states of chemical combination in soils, depending largely on the degree of acidity and aeration of the soil.

In acid soils, Mn can reach toxic levels but is relatively rare with pastoral soils in New Zealand. In general, levels need to be above 400mg/kg DM (ppm) before they affect animal production. With herbage such as lucerne and brassica, Mn levels as low as 200-300 ppm may affect growth. Applications of lime can reduce manganese toxicity.

With soil pH values above 6.5, Mn availability for crop growth falls rapidly and Mn deficiency can develop. Mn deficiency sometimes occurs with cereals in Canterbury on high pH soils, but elsewhere is unlikely in New Zealand. Deficiency can be a problem in horticultural soils, particularly in citrus and stone fruit orchards. Maintaining an optimum pH for each enterprise is very important. To ensure that the pH stays within the desired range, monitoring by regular soil testing should be carried out.

LIME BEING DROPPED INTO STORAGE

6.8.7 Molybdenum

Molybdenum is an essential nutrient for both plants and animals. Its importance in plants is due mainly to its presence in two enzymes, nitrogenase for N fixation and rhizobium function and nitrate reductase for controlling the conversion of nitrate N to amino acids for protein construction.

In New Zealand, Mo deficiency occurs in both clovers and lucerne. Substantial increases in pasture production have been obtained from Mo application. Other legumes are also susceptible to Mo deficiency, along with some brassicas like cauliflower and broccoli.

Soil Mo availability to plants increases with pH. In many soils Mo deficiency may be removed by liming to pH 5.5 to 6.0. A high proportion of lime responses in New Zealand is partly due to the correction of Mo deficiency.

Some soils are so deficient that no amount of liming will guarantee the adequacy of this essential micro-nutrient. On deficient soils, 50 grams of sodium molybdenate per hectare should be applied every 4 years. This rate will correct molybdenum deficiency and give the maximum dry matter yield without producing dangerously high molybdenum concentrations in the herbage.

LIME ROCK TO BE PROCESSED INTO LIME

High concentrations of molybdenum can adversely affect stock health through depressing copper absorption. Many areas of New Zealand eg. Northland and Gisborne (Wairoa) suffer from Mo induced Cu deficiency. Care should be taken in monitoring Mo status of pastures before Mo is applied. In most cases liming alone will adequately increase the Mo status of herbage.

6.8.8 Copper

Copper (Cu) is involved in many plant processes. It is essential for photosynthesis, protein production and carbohydrate metabolism. It is also required for N fixation by rhizobia bacteria.

Copper deficiency occurs on organic soils, strongly leached sandy soils, and podzolised soils. Deficiencies in grass/clover pastures have also been observed on the yellow-brown pumice soils of the Central Plateau. This deficiency is not related to soil pH and occurs in both acid and alkaline soils.

High molybdenum levels increase the risk of “induced” Cu deficiencies. Molybdenum levels can be safely managed as discussed in 6.8.7.

Raising the soil pH to above 6.5 by heavy liming is likely to accentuate copper deficiency.

6.8.9 Boron

Boron (B) does not appear to be required for animals but deficiencies affect many horticultural and agricultural crops in New Zealand. Boron appears to be essential for the development and growth of new plant cells. Plants affected by B deficiency include swedes, turnips, lucerne, apples, stonefruit and radiata pine. Pastures are rarely affected by B deficiency.

The availability of B to plants generally decreases with an increase in soil pH. Soil pH’s above 6.5 are likely to be most susceptible to B deficiency. Caution is needed when lime is applied to soils which are susceptible, as overliming may induce boron deficiencies.

Boron should only be applied when deficiency has been confirmed by soil or plant analysis, and then only in recommended quantities as B toxicity can be a factor. Many crops are very sensitive to excess B. Application of B to the soil will prevent deficiency in the subsequent crop and make it possible to apply lime when needed.

6.8.10 Calcium

Calcium (Ca) is a very important plant and animal food. Its presence in the soil is essential to ensure the absorption and movement of growth elements such as phosphorus, magnesium and nitrogen. Clovers have approximately double the concentration of Ca as grasses. For clover nodulation to occur, Ca must be present in adequate amounts.

Calcium is a fundamental constituent of limestone, as discussed in section 6.4 and its availability to plants increases in alkaline soil.

6.8.11 Zinc

Zinc (Zn) is an essential element for both plants and animals. In plants it is present in many important enzymes. Zinc promotes growth hormones and starch formation and it is involved in seed production.

In New Zealand, deficiencies are rare in agricultural crops and livestock. The odd deficiency occurs in pasture and wheat crops in the South Island as a result of overliming. Zinc deficiency however is quite widespread in fruit orchards especially citrus and stone fruit. The symptoms are similar to Mn deficiency.

At very high pH (pH>7.0) the availability of Zn to plants decreases significantly. It is particularly important in horticulture to monitor pH before applying lime and running the risk of overliming.

TRUCK SPREADER

6.8.12 Iron

Iron (Fe) has many important functions in both plants and animals. The availability of Fe decreases in soils above pH 6.0. Iron deficiency in pastures, crops and livestock is extremely rare in New Zealand. Induced deficiencies from overliming can occur in some horticultural and nursery crops.

6.8.13 Cobalt

Cobalt (Co) is an essential nutrient for grazing livestock. There is widespread Co deficiency in animals throughout New Zealand. Soil Co availability to plants is very sensitive to both soil pH and soil moisture status. Like manganese and copper, its availability is greatest when the soil is acid. Overliming can result in deficiency on some soils. Cobalt sulphate in fertiliser is widely used to overcome soil and animal deficiencies. Vitamin B_{12} injections are also used for stock.

6.8.14 Magnesium

Magnesium (Mg) follows similar trends to calcium with regards to pH and is more readily available to plants in more alkaline soils. Above pH 7.0 Mg reaches its maximum availability to pastures and crops but raising the soil pH as high as pH 7.0 may limit the availability of other nutrients to plants.

Magnesium deficiency in pastures is not common in New Zealand at present, but there is increasing evidence to suggest that soil test Mg levels are falling. Magnesium fertiliser inputs are required on many soils to halt this decline. On high producing dairy farms in Ruakura, data suggests 20kg Mg/ha/year is being leached from soils and not replaced. This is particularly a problem on volcanic and podzolised soils with little Mg reserves.

Negative responses to liming have been found in situations where wide Ca:Mg ratios occur. The soils in the southern South Island seem to present particular risks in this regard. Trials on Southland silt loam which had wide Ca:Mg ratios showed reliming was harmful, causing lowered white clover growth. This situation is not considered to be widespread.

Of more concern is the effect that the timing of lime application can have on the Mg status of the pasture. Research in Taranaki has shown a late autumn/early winter (May) application of lime at 5 tonne/ha had a dramatic effect on animal Mg status in early spring leading to hypomagnesaemia in dairy cows. It is suggested that liming should be done mainly in the late spring-summer-autumn period to avoid any animal health problems.

6.8.15 Potassium

On most North Island soils, especially those from volcanic ash, liming neither significantly enhances nor decreases the potassium (K) uptake by plants.

In a study testing the effect of lime on potassium leaching A.S. Black and I.R. Phillips (Department of Soil Science, Lincoln University) found that low lime application reduced leaching of K added after liming. At higher rates of liming, the beneficial effects of lime on K fertiliser leaching were reduced.

6.8.16 Relative frequency of deficiency

The relative frequency of deficiencies in pastures is: (in descending order)

- Nitrogen (N)	(incompletely corrected in grasses by clover)
- Phosphorus (P)	Annual maintenance
- Potassium (K)	applications are needed on
- Sulphur (S)	deficient soils.
- Molybdenum (Mo)	Occasional applications only
- Copper (Cu)	
- Magnesium (Mg)	
- Boron (B)	
- Zinc (Zn)	

Deficiencies other than N, K, P, S and Mo are relatively uncommon in pastures. B deficiency is much more common in brassicas and lucerne than in white clover.

Problems associated with manganese (Mn), iron (Fe), and zinc (Zn) deficiencies are very rare or insignificant in New Zealand.

6.8.17 Nutrient deficiency symptoms

Plant leaves showing deficiency symptoms are usually very low in the deficient nutrient. Conversely toxicity symptoms are associated with abnormally high values. Occasionally symptoms agree exactly with textbook illustrations but at times can vary. Visual diagnosis alone is therefore not advised.

If a pasture nutrient deficiency is suspected it is best to take a 'clover only' sample for full nutrient analyses. Taking a sample from a 'good' and 'poor' area helps in the diagnosis. If an animal health problem is suspected, take a representative sample of the feed on offer to the animals and get it analysed under an animal health profile of tests. The 'Optigrow programme' offered by veterinarians comes into this category and includes animal tissue analysis.

Nitrogen deficiency produces pale green foliage, rather than the definite yellowing indicating sulphur deficiency. Additional reddish colours commonly appear in most brassica and oat varieties. Legumes showing pink tints of pale foliage colour are usually low in nitrogen.

The most common causes of nitrogen deficiency in legumes are:

- poor nodulation
- Mo deficiency
- S deficiency
- B deficiency in lucerne

Brilliant red colours in subterranean clover are usually due to fungal or bacterial root injury.

Potassium deficiency causes characteristic white or brownish spotting on clover and lucerne leaves, followed by leaf death. The spotting symptom is not always present. White clover may show marginal leaf burn. In many cases, only isolated plants and older leaves are affected. These do not necessarily indicate an economically significant potassium deficiency. In maize and brassicas, marginal and tip leaf-burn is present. In beets and potatoes, foliage shows bronzing and crinkling. In potatoes this is followed by premature leaf collapse.

Potassium deficiencies in white clovers show variable symptoms:

(a) Summer: On the upper surface of the older leaves, numerous small white to pinkish cinnamon coloured spots. Dead areas develop on the edges of these leaves and gradually spread until the whole leaf dies.

(b) Summer/Winter: On either side of the midribs of the oldest leaves, the development of the dead areas on the leaf edges beginning as pinkish-cinnamon spots.

Sulphur deficiency tends to give yellow green or yellowish foliage. In white clover the yellowing of the leaves often starts with the youngest clovers.

Phosphorus deficiency symptoms can cause bronzing of clover leaves but may cause no other obvious symptoms other than stunted growth. In white clover phosphorus deficiency may be indicated where plant growth is very dwarfed and dark green in colour. Old leaves become pale yellow and die. With time all leaf stalks develop a slight purplish pink colour.

When nitrogen is adequate, phosphorus deficient grasses are usually darker than normal. In some plants such as brassicas, violet colours may appear. In late autumn these may just be indications of “ripening”, excess sugars being stored as coloured anthocyanins. This “symptom” can also appear in early plantings of some plants such as maize in sunny but cold weather, which permits photosynthesis of sugars but prevents their utilisation for growth. Therefore reddish or purple colours are not specific symptoms, but merely indicate a build-up of sugars.

Molybdenum plays an important role in nitrogen fixation by legumes. Severely **molybdenum deficient plants** are pale green to yellow in colour, have poor leaf formation and have stunted growth. Pastures lack in fertility and revert to low fertility grasses. All these conditions reflect the nitrogen deficient state of plant and soil.

Copper deficiency causes leaf collapse in white clover and other plants, the dead tissues assuming a whitish or bleached appearance, resembling urine ‘burn’. Copper deficiency in white clover may also resemble wilting, with folding of individual leaves.

Boron deficiency causes a reddening of lucerne leaves and gives a ‘leathery’ feel to the leaves. Deficiency symptoms are most apparent during periods of moisture stress. In brassicas deficiency causes ‘ brown heart’ and in apples ‘corky pit’.

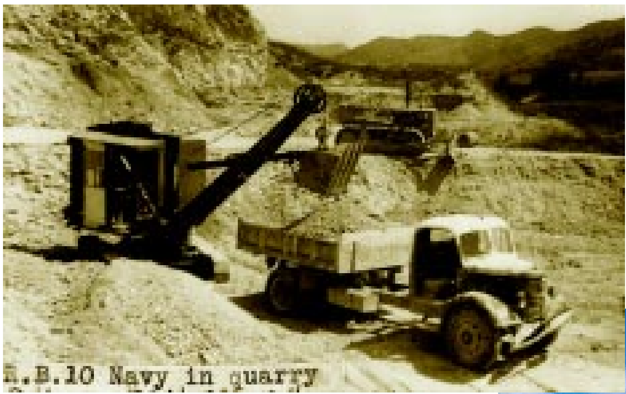
7.0 Soil pH Preferences of Crops

When deciding upon a liming programme for a given soil type, it is of prime importance to take into account the type of crop to be grown. Plants differ widely in their response to added lime. The nature of this response is not always known, but it is a matter of common observation that certain plants will grow well in acid soils, whereas others prefer more alkaline soils.

The following list of pH ratings of soil most suited to different crops, vegetables, trees and flowers, has been compiled by leading world authorities, and shows that a high percentage of crop plants have their optimum range around pH 6.5.

Table 7. Optimum Soil pH Ranges for Crops

Plant	pH	Plant	pH
Wheat	5.5 - 6.5	Cabbage	6.0 - 7.5
Barley	5.8 - 6.5	Carrot	5.5 - 7.0
Beans (field)	6.0 - 6.5	Cauliflower	6.0 - 7.5
White clover	5.6 - 6.0	Lettuce	6.0 - 7.0
Red clover	6.0 - 6.5	Potato	4.8 - 6.5
Ryegrass	5.5 - 6.0	Tomato	5.5 - 7.5
Oats	5.0 - 6.0	Apple	5.5 - 6.5
Peas (field)	6.0 - 6.5	Strawberry	5.0 - 6.5
Asparagus	6.0 - 6.5		



8.0 Loss of Lime From the Land

Since calcium is an essential plant nutrient, it enters the composition of all crops, either directly or through the feeding of livestock. This leads to the depletion of the soil's lime reserves.

Legumes remove calcium from the soil. Two tonnes of clover or lucerne may take 30-50kg of calcium. Losses range from 10-20kg calcium/hectare in cereals, to 150kg/hectare or more in good crops of kale.

High producing dairy farms send large amounts of calcium away every year in their milk (2.25kg calcium in 1000 litres).

Conserving silage and hay depletes calcium levels in those soils. When crops or animals are sold off the farm, calcium is completely lost, but where crops are used on the farm a significant amount of calcium will be returned in farmyard manure, though a proportion will be lost in drainage from sheds.

In practice the losses of lime caused by leaching, and by the use of fertilisers that acidify the soil, are much more important than losses caused by sales of crops and stock.

8.1 Drainage losses

Rainwater charged with carbon dioxide and sulphur dioxide in varying amounts dissolves some of the lime in the soil, a proportion of which finds its way into the drainage system and is therefore lost from the soil. The rate of loss depends on the rainfall, the texture of the soil and the amount of calcium in the soil. Losses vary from 100-1000kg/ha of calcium carbonate annually. Losses are higher under arable cropping than under grass. Bare arable land in winter is particularly vulnerable.

As lime moves downward in drainage water, it is quite possible for the surface soil to become acid, irrespective of the nature of the subsoil. The movement of drainage water tends to be uneven, and some areas of soil lose lime more rapidly than others; this may lead to variations in acidity. For this reason the first observable effects of acidity in a crop are often patchy.

8.2 Lime losses and soil type

The relative proportions of sand, clay and organic matter in soil influence the retention of lime. Light sandy soils have the lowest capacity for holding calcium, and as they are usually freely drained, the calcium is rapidly leached from the soil. It is on these soils that troubles from acidity are most common and most acute, but easily remedied. Small dressings generally suffice to restore very acid and sandy soils to neutrality. By contrast, clay soils or those rich in humus can hold much larger quantities of calcium. This calcium is tightly held in the soil, and drainage losses over many years are required for its removal.

8.3 The effects of fertilisers on soil acidity

8.3.1 Ammonium fertilisers

Sulphate of ammonia has long been recognised as being an 'acid fertiliser' and produces some residual acidity. All NH_4 fertilisers, and those which produce NH_4 like urea, create residual acidity. The reason this occurs is because when NH_4^+ is oxidised to NO_2^- and NO_3^- in the soil there is a release of H^+ ions and an increase in acidity. In addition, when NO_3^- is leached from the soil it is accompanied usually by calcium.

SETTING BLASTING EXPLOSIVES

8.3.2 Urea

Urea when applied to the soil rapidly hydrolyses to NH_3 and NH_4^+. Some of the N can be lost through volatilisation as ammonia but the bulk of the NH_4^+ will oxidise through to NO_3^- (nitrification) and release H^+. Acidification will not be as severe as from sulphate of ammonia.

8.3.3 Superphosphate

Superphosphate contains 20% Ca so is a useful source of Ca to the soil. Long-term trials have shown that Superphosphate does not in itself have an acidifying effect on the soil. It is the products of fertiliser use i.e., legume production that tends to acidify the soil together with the other processes noted previously.

Most organic wastes supply some calcium to the soil. The N contained in these materials is in a slow release form but will eventually cause some acidification to occur.

Nitrogen fertilisers will have an acidifying effect on the soil whenever ammonium nitrogen is converted in the soil to nitrate nitrogen. Lime is needed to neutralise this change in acidity. Overall it is clear that the use of nitrogenous fertilisers cause the acidification of soils which will limit the growing potential and sustainability of healthy, productive soils. Lime is needed to counteract the acidifying effect of such fertilisers.

9.0 Factors Influencing Pasture Responses to Lime

The extent to which pasture and crop production increases can be expected from a given quantity of lime is a very important parameter when calculating lime requirements and economics. Many soil properties, management practices and environmental conditions work together to form a somewhat complex picture of lime responses. By understanding many of the factors which contribute to lime responses farmers and advisors may be better equipped to make more accurate predictions for lime requirements.

9.1 The natural supply of lime to New Zealand's soils

The natural supply of lime to the soil depends partly on the chemical composition and partly on the physical character of the parent material from which the soil has developed.

LIME STORAGE SILOS

An adequate supply of lime in the soil is essential for crop growth and susceptible crops grown on strongly acid soils give low yields. The range of pH in unlimed topsoils of New Zealand is 4.5 to over 6.0, excluding peats which may be very acidic with pH 4.5 or less.

From the large number of trials which have been conducted in both the North and South Islands, a general picture emerges of increasing need for lime on soils of decreasing pH, and for greater frequency of treatment under conditions of stronger leaching.

9.2 Calcium availability in the soil

In some cases soils may seem to be measuring an optimum pH (e.g.6.1) for plant growth, yet suffer from low availability of calcium. In this situation liming even above pH 6.1 can be beneficial for good production and highly economic. This will have implications for horticultural soils in particular.

9.3 The organic matter content and the pH buffering capacity of soils

Soil pH values measure the intensity of acidity and do not indicate the quantity of lime needed to bring soils back to the neutral point. Lime neutralises both H^+ ions in solution and H^+ ions on the soil colloids. To become neutral a soil will use up more calcium carbonate ($CaCO_3$) than can be calculated from the estimated amount of H^+ ions in the soil solution (i.e. the pH measurement). This added effect which causes the soil pH measurement to resist change when lime materials are added, is called pH buffering.

The capacity of soil to buffer its pH (i.e. resist change in soil acidity) depends on how much acidity is held on the soil surface. It depends on its cation exchange capacity (CEC).

The CEC is the amount of exchangeable calcium, together with other plant nutrients that a soil can hold. Having a higher CEC is beneficial in that it can decrease the amount of valuable nutrients leaching from the soil. Liming is the principal management practice which is known to increase the CEC through its effects on pH. More lime is required to bring the pH of the soil to its optimum value when its CEC is higher than when it is lower.

Previously, it was commonly accepted that buffering capacity of the soil was dependent on its clay and organic matter content. And that a change in soil pH produced by a lime application was influenced by the texture of the soil. Coarse textured soils (sands) were considered to require less lime for a given rise in pH than the fine textured soils (clays).

Research on 95 different soils (Edmeades et al. 1984a) found that there were surprisingly no significant differences ($P=<0.05$) in soil pH, delta pH (an indication of buffering capacity) or lime response between volcanic and sedimentary soil groups overall. This can now be understood by finding that lime responses are related to soil pH and that this relationship is similar for both volcanic and sedimentary soils. At the same soil pH the size of pasture responses to lime were similar. In practice however, the volcanic soils typically have higher pH (5.6-5.7) than sedimentary soils (5.3-5.5) in their unlimed state.

When the soils were categorised according to soil texture it was found that clay and clay loams were more responsive to lime than the other classes of soil (sands, sandy loams, silt loams). This can be explained by more recent research on similar New Zealand soils (Edmeades et al. 1984c) which has shown that soil lime requirements are a function of delta pH (buffering capacity) and are not related to soil organic matter, but to soil texture. These results are consistent with overseas studies.

9.4 Seasonality in pasture growth responses to lime

Research into pasture growth responses to liming have identified that the degree of response varies between seasons. The greatest pasture growth response usually occurs in summer or autumn, regardless of when the lime is applied. The smallest response is usually in spring.

From six lime trials examining the seasonal response of pasture to liming the following average values were recorded. See Table 8.

Table 8. Seasonal Increases in Pasture Production

Season	Months Included	Mean Seasonal Increase in Pasture Production
Autumn	March, April, May	17%
Winter	Jun, Jul, Aug	11%
Spring	Sept, Oct, Nov	5%
Summer	Dec, Jan, Feb	13%

The reasons for seasonal response patterns are poorly understood, and further research work is required before useful methods for the prediction of seasonality in lime responses can be derived.

There are many possible explanations for seasonality, which include the following:

1) Liming reduces exchangeable aluminium levels in soil, which in turn reduces or eliminates the toxic effects of aluminium on root growth. Thus during times of moisture stress such as the late summer - autumn period, improved root growth which enables a

greater volume of soil to be exploited may account for the increased pasture growth responses to lime over those recorded in wetter seasons.

2) Liming has been observed on several occasions to result in a change in pasture composition.

3) Liming has in some cases been found to improve the rapidity with which dry soils rewet following rainfall.

4) In situations where liming improves the availability of phosphorus, seasonal variation in soil pH status could also contribute to the seasonality of lime responses.

9.5 Effect of the stocking rate

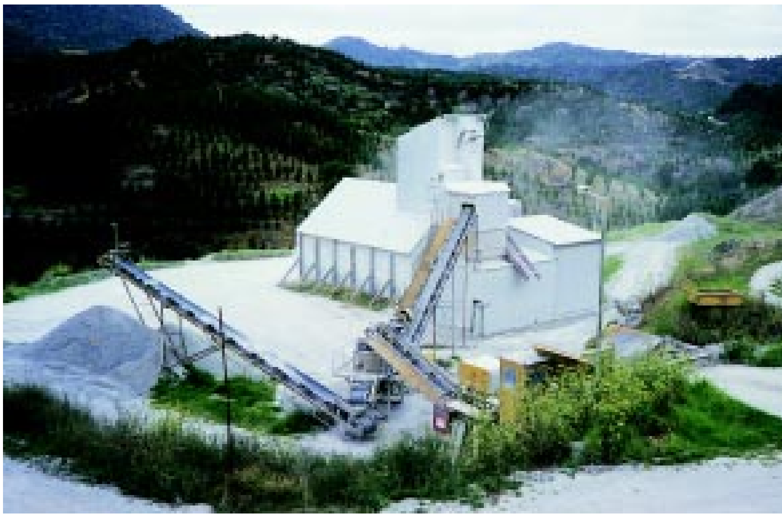
Lime trials have found that responses to lime in pasture and animal production were greater at higher stocking rates. To achieve the maximum response to liming, stocking rate (and hence pasture utilisation) must be maximised.

9.6 Factors influencing the speed of reaction of lime in the soil

A particle of lime in contact with the soil will dissolve at a rate which is dependent on many factors. One of the most important factors is the surface area of the lime particle. This increases in almost direct proportion to the fineness of grinding. At any given constant weight, if the particle size is halved, the surface area is doubled. Other things being equal, fineness of grinding has a very large bearing on the rapidity with which liming affects plant growth and soil pH.

Agricultural limestone usually has a wide range of particle sizes. This is a desirable feature unless too large a proportion of particles is so coarse that under most conditions little is dissolved for many years. It is still the practice of lime millers in New Zealand to adhere to the previous M.A.F Lime Transport Subsidy (LTS) requirements for grinding, namely: $< 5\% > 2$mm and $> 50\% < 0.5$mm. Farmers should ensure that they sight recent analyses of the lime they intend to purchase and thus help to maintain these grinding standards.

There are also many other factors, which influence the effectiveness of lime over a given period. Some of these are as follows; original soil acidity and degree of original saturation with calcium, rate of application of lime, closeness of contact of lime particles with the soil solution, soil moisture levels, temperature, and the rate at which dissolved calcium is removed from the immediate vicinity of the particles of the origin.



TYPICAL LIME PLANT

9.7 Timing and placement of lime

Lime can be applied at any time of the year with effective results. Research in Taranaki (Thomsen) has shown that late autumn/early winter applications can adversely affect the Mg status of cows in spring and is thus not recommended. For this reason, on some soils the time of the application is determined in part by the times of the year the land will carry tractors and spreading equipment. Aerial spreading is not restricted in this manner except as regards airstrip conditions or suitable flying weather.

Even on very acid soils on which pasture plants do not survive without lime, establishment is good if lime is applied at the time of sowing.

A few experiments have been carried out comparing top dressing with dicing in or ploughing in. On deep acid peats, where roots fail to penetrate into the unlimed layers, deep ploughing of lime has proved essential. On the other hand, there is no evidence as yet that on mineral soils the incorporation of lime into the soils offers advantages over top dressing.

9.8 Spreading lime

The most efficient method available for spreading lime is through bulk application by the supplier, who transports the lime to the farm. The spinner truck spreader, which throws the lime in a semicircle from the rear of the truck, is often used. Uniform spreading is more difficult with this equipment than with machinery, which drops the lime from a covered hopper or conveyer. Particularly on hill country pasture, it may be necessary to employ an aerial spreader. Aerial spreading is likely to be a much more expensive operation.

Regardless of the method employed, spreading should ideally be as even as possible. Not only because local shortages may result in patchy crops, but also because the thinner the dressing is in some parts of the field, the sooner it will become exhausted and require further liming. An examination of the distribution pattern at the start of the operation is helpful in correcting non-uniform spreading and providing proper lapping.

9.9 Frequency and application - assessing soil nutrient status

Capital lime inputs can be many times greater than maintenance inputs, especially if a rapid increase in soil nutrient status is required. It is important to measure the existing soil nutrient status to assess whether a farm is in the development or maintenance phase. Soil testing and taking into account fertiliser and lime history is the only way to do this.

In a normal farm situation, soil sampling should be undertaken at least once every 2 to 3 years.

The following soil tests are available from most commercial laboratories:

pH, Olsen P, K, Mg, sulphate-S, organic-S, anion and cation storage capacity.

These soil tests are used for the following purposes:

* pH-a measure of soil acidity and hence a test for lime requirement.
* Olsen P- a measure of plant available phosphorus.
* Anion storage capacity (ASC)- a measure of the capacity of soil to store nutrients such as P and S.
* Cation storage capacity (CSC)- a measure of the capacity of the soil to store nutrients such as Ca, Mg, K and Na. (Also referred to as cation exchange capacity.)
* Quick Test K (QTK)-a measure of plant available potassium (K).

* Quick Test Mg (QTMg)-a measure of plant available Mg.
* Sulphate-S (SO_4-S)-a measure of the immediately available S.
* Organic-S (Org-S)-a measure of the long-term supply of S.

9.10 Development phase

New Zealand soils are inherently deficient in P, S, to a lesser extent K, and sometimes trace elements. In the development phase the soil is initially very acid. Large capital inputs of fertilisers and lime are required. Initially 4-5 tonnes per hectare of lime is needed to bring the pH of the soil up to optimum as quickly as possible. At this level the soil is better able to utilise any fertiliser that is applied.

With the passage of time and recycling of nutrients through grazing animals, a build up of soil nutrient reserves and organic matter will occur. The development process may take many years, especially if initial inputs of lime and fertiliser are not large.

Eventually, further increases in soil nutrient status will result in only relatively small increases in production. A soil nutrient status will be reached at which near maximum pasture production occurs. Farms at this stage of development can be regarded as being in the maintenance phase.

9.11 Maintenance phase

During the maintenance phase, lime and other fertilisers are required simply to replace the inevitable losses of nutrients which occur in soils.

Once the desired pH has been achieved it can be maintained either by applying a relatively large rate of lime less frequently (e.g. 2.5 tonnes/ha every 3-6 years), or a smaller quantity of lime more often (e.g. 1 tonne/ha every year).

TYPICAL LIMESTONE QUARRY

The results of three years of lime trials at Waiotira (Lovegrove trials) indicated that there was no advantage (or disadvantage) in applying small amounts of lime annually as opposed to applying large amounts less often. In terms of maintaining the soil pH it does not matter which practice is adopted although it is probably more economic, because of spreading costs, to apply the larger rate less frequently.

9.12 Duration of responses

Assessment of the economic benefits of liming, in particular the calculation of the appropriate economic rate, requires information on duration of lime responses.

The duration of the effect of lime on soil pH has been found to be related to rainfall. The duration of the response to liming, at three different rates of application, can be calculated from the information in Table 9.

Table 9. Duration of Lime Responses

Lime application rate (tonnes/ha)	Duration of response (years)
1.25	6-(0.0012 x mm of rainfall)
2.5	8-(0.0012 x mm of rainfall)
5	10-(0.0012 x mm of rainfall)

The effect of a single application of 2.5 tonnes/ha of lime on soil pH will last at least 6 years. How much longer would seem to depend both on soil group and on individual site effects.

Table 10. shows relationships between soil pH and pasture DM response to lime at 3 rates. For simplicity this table is based on the assumption that the optimum pH for this soil is 5.9. The responses noted are for raising soil pH from 5.1 to 5.9 and are average values from trials throughout NZ. Many soils will have a higher optimum pH (e.g. optimum pH of 6.1 - 6.2). In such situations this table is not appropriate for calculating % response.

Table 10. Relationships between Soil pH and Pasture DM Response

% response to 1.25 tonnes/ha = 8.9 (5.9 - soil pH)
% response to 2.5 tonnes/ha = 10.8 (5.9 - soil pH)
% response to 5.0 tonnes/ha = 13.54 (5.9 - soil pH)

10.0 Calculating the Desirable Rate of Lime Application

10.1 Liming recommendations for pastures on mineral soils

The most profitable rate of lime to apply for each individual farm situation depends on the farm's soil type, soil management, and economic situation. It is not possible to make general recommendations that will be accurate for each individual situation.

The profitability of liming is sensitive to changes in farmer input such as stocking rate and gross margin. It is strongly recommended that as part of the decision making process, farmers, through their local advisors, calculate the effects on profitability of changes in these inputs for each given farm situation.

On ash and pumice soils the following general guide applies.

10 tonne/ha of quality limestone will raise the soil pH by 1 unit (e.g. pH 5.0 to 6.0) or, for each tonne per hectare applied, the soil pH will rise by 0.1 unit (e.g. pH 5.5 to 5.6).

Various consultants are available with the necessary computer software to complete these calculations quickly and easily. These calculations can also be done manually. An example of the inputs required to undertake the calculations of net present values for a typical farm situation is given in Example 1 (overleaf). To complete these calculations it is necessary to refer to tables A, B, C and Table 10. (% response) with Table 9. (duration of response) for a summary of the required input data and the calculations to be made. In many situations the greater benefit will be obtained from higher rates of application as a direct consequence of the longer duration of response at those rates. It is precisely this area where research data is scarce and the equations for the duration of response should be considered as tentative.

Example (1) What is the economically optimum rate of lime to apply to a farm on gumland soils with a low pH of 5.2, a high annual rainfall of 1000mm and currently carrying 11 s.u/ha? For this example we will assume that the optimum pH for this particular soil is 5.9, therefore we can use Table 10. to calculate % response.

From the input data in Table A and the information in Tables 9. and 10. (see section 9.12 for Tables 9. and 10.) the calculations shown in Table B can be made.

The flow of benefits (for 1.25 tonnes/ha only) is shown in Table C. Net present value, i.e. the sum of the present value of net benefits, equals $254/ha. Similar calculations for the two lime rates, other than that in Table C, give:

- 2.5 tonnes/ha 7 years duration $435/ha net present value
- 5.0 tonnes/ha 9 years duration $626/ha net present value

For the given inputs liming is economic at all three rates, however the optimum rate of application for this hypothetical situation is 5.0 tonnes/ha, 9 years duration at $626/ha net present value.

Table A. Input information

1	Annual rainfall (mm)	1000
2	Soil pH	5.2
3	Lime cost ($/tonne)	12.00
4	Freight to farm ($/tonne)	13.00
5	Application costs at each application rate ($/tonne) 1.25 tonnes lime	12.50
6	Dry matter 1 s.u. (kg) Takes 14kg DM to produce 1kg of milksolids	520
7	Profit from 1kgMS ($)	3.60
8	Dairy Stock Unit price ($)	120
9	Present stocking rate (s.u./ha)	11
10	Gross margin ($/s.u.) (calculation: G X F = $62.10/s.u.)	62.10
11	Cost of increasing stock ($/s.u.)	120
12	Stock salvage value (25% of initial cost)	30.0
13	Discount rate (%)	7.5

Table B. Calculation of Economics

A	Lime rate (tonne/ha)	1.25
B	Response (%) (Table 10.)	6.23
C	Extra stock/ha (11 x B/100)	0.69
D	Lime cost in $/tonne (3+4+5)	37.5
E	Lime cost in $/ha (')x rate)	46.8
F	Extra stock cost in $/ha (C x 120)	82.8
G	Annual benefit (C x 25)	90
H	Duration of benefit (Table 9.)	5
I	Salvage value (C x 30)	20.7

Calculations for annual benefit:

0.69 s.u. x 520kgDM = 358.8kgDM

358.8kgDM/14kgDM = 25kgMS/ha

25kgMS/ha x $3.60 = $90/ha

Table C. Flow of Benefits (for 1.25 tonnes/ha)

Parameter	**Year**					
	0	**1**	**2**	**3**	**4**	**5**
Lime cost/ha	47					
Extra stock costs		82.8				
Annual benefit/ha		90	90	90	90	90
Salvage value/ha						20
Gross benefit	-47	7.2	90	90	90	110
Net benefit	**-47**	**7**	**78**	**72**	**67**	**77**

Note- The Benefit = $\frac{\text{Gross benefit}}{1.075^{year}}$

Notes on calculations of economics

From the foregoing the following points can be made:

(a) It is assumed that the effect of liming on animal production can be predicted from its effects on pasture production.

(b) If the aim is to achieve improved performance per head without increasing stock numbers the cost of extra stock will be zero, i.e. income from improved performance is equated to the income from extra stock.

(c) Annual economic benefit ($/ha) is gross margin/ha. Annual benefits are accumulated for the duration of the response. The salvage value of extra stock, if purchased should be added.

10.2 Liming recommendations for pastures on peat soils

Peat soils are classified as those with more than 40% organic carbon in the top soil. Peaty loams have 20-40% organic carbon.

Soils rich in organic matter, such as peats usually grow satisfactory crops at slower pH values than mineral soils do. This is because organic soils have a larger capacity to hold exchangeable bases.

Economics

Pasture responses to liming are large on peat soils with a pH lower than that required for optimum production. On such soils liming is therefore essential and probably always economic for pasture development. The procedure for calculating the most economic liming rate for mineral soils does not apply to peat soils.

Liming peat soils can give quite outstanding results which can last for many years, but as the saying goes:

"Too much lime and no manure makes the father rich and the son poor".

Subsoil lime
The subsoil pH of most peats is very low, often 3.5-4.5. Surface applied lime does not move down into the subsoil, so in order to significantly increase pH below a depth of 75mm, lime must be incorporated into this region. Lime can only be mechanically incorporated when pastures are being resown.

An important consequence of deep liming is that pastures are better able to tolerate moisture stress in the summer. This occurs because during 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.

Lime requirements
To achieve good production, the pH of the subsoil (75-150mm) needs to be at least 4.5. For pasture establishment and maintenance, a minimum pH of 5.0 at 0-75mm and 4.5 at 75-150mm is recommended. However there have been only a few trials, so on these soils the precise relationship between soil pH and pasture response to lime cannot be firmly established.

When renewing old pastures it is beneficial to apply more lime to the acid peat that is brought to the surface during cultivation.


LIME PULVERISER

The amount of lime needed to achieve minimum target pH values can be calculated from the data summarised in Table 11. (please see over). Examples below show how this is done.

Note: The target pH values given are minimum only. As peats mineralise, the optimium pH rises to eventually become similar to mineral soils.

Example 1 - Virgin peat, pH 4.0, deep liming required
The pH should be raised by one unit to 5.0 in the topsoil (0-75mm) and by 0.5 units to 4.5 in the subsoil (75-150mm).
It would take 17 tonnes of lime per hectare to raise the subsoil pH by 1 unit. However, as 8.5 tonnes will be applied, the topsoil pH will in fact be raised by 8.5/7=1.2 units, giving a pH of 5.2.

Example 2 - Developed peat, pH 4.5, deep liming required
Pasture will be resown, so that lime can be incorporated into the soil. The topsoil pH should be raised by 0.5 units. This will require 16 x 0.5 = 8 tonnes of lime per hectare (Table 11.) of which one half is to be incorporated into the soil.

The subsoil pH will incidentally be raised by 8/34 = 0.2 units giving a pH of 4.7.

Example 3 - Developed peat, pH 4.5, surface applied lime
Pasture will not need to be resown, therefore lime can only be surface applied. The topsoil pH should be raised by 0.5 units. This will require 9 x 0.5 = 4.5 tonnes of lime per hectare.

Table 11. Effect of Application Method and Degree of Peat Development on Lime to Raise pH of Organic Soils by 1 pH unit.

Application method	Soil depth	Lime application rate (tonnes /ha)	
		Virgin Peat	Previously developed peats and peaty loams
Surface applied	0 - 75mm	-	9
	75 - 150mm	-	No effect
50% incorporated	0 - 75mm	7	16
50% surface applied	75 - 150mm	17	34

Maintenance requirements

Recent research on peat soils in the Waikato has indicated that as these peat soils mineralise and become more like mineral soils, then their optimum pH requirements also increase to 5.8-6.0. A P retention or ASC (Anion Storage Capacity) soil test done by most laboratories will assist in deciding when a peat soil has mineralised through to a mineral soil.

No information is available on the amount of lime required to maintain soil pH on developed peat soils. It is suggested that soil pH should be monitored every 2-3 years. On areas due for cultivation soils should be sampled at two soil depths: 0-75mm and 75-150mm.

Bibliography

Aglink Information Pack, Soil and Fertilisers Vol 2.

Annabell R, April 18 1994, Hill country farmers cry out for lime, Rural News Pg 27, Hill country must have lime to survive, Pg 38.

Bolan N.S, Hedley M.J, White R.E, 1991, Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures, Fertiliser and Lime Research Centre, Massey University.

Carran R.A, 1992, Managing soil acidity: Old solutions can cause new problems, Proceedings of the New Zealand Grasslands Association 54: Pg 77-80, AgResearch Grasslands.

Cooke G.W, 1975. Fertilising for maximum yield. 2nd edition, Agricultural Research Council.

Comforth 1.5, Sinclair A.G, 1984, Fertiliser recommendations for pastures and crops in New Zealand, 2nd Edition, Ministry of Agriculture and Fisheries.

Dairying Today, March 1992, Lime increases clover and decreases weeds. Pg 2 Davis B,

Eagle D, Finney B, 1972, Soil Management, Farming Press Limited.

Edmeades D.C, Pringle R.M, Mansell G.P, Shannon P.W, 1984, Summary of all lime trials, M.A.F Agricultural Research.

Groundspread Feature, October 1996, Lime research trials mature, Pg 14.

Hunt B.J, O'Connor M.B, 1996, Lime research in Northland, Field Trial results - Lovegrove J&M. Waiotira 1993-96, Other lime trials in Northland 1990-1993, AgResearch in conjunction with Northland Lime Millers and Hinerangi Trust.

Jackson B.L.J, Edmeades D.C, 1985, Proceedings of work shop on Lime in New Zealand agriculture, New Zealand Ministry of Agriculture and Fisheries.

Jaiyou Z, 1993, Response of North Island hill country pasture to nitrogen molybdenum and lime. (Thesis).

Levy E. Bruce, kt., O.B.E., D.Sc., 1955, Grasslands of New Zealand, Technical correspondence school. New Zealand Department of Education.

McLaren R.G, Cameron K.C, 1990. Soil science. An introduction to the properties and management of New Zealand soils. Pg 294. Oxford University Press.

Martinus N, Junk W, Efficient use of fertilisers in Agriculture, Developments in plant and soil science Vol 10, United Nations Economic Commission for Europe.

Martyn R, Dairying Today, October 1992, Lime facts and fallacies, Pg 17, 20.

Northland Farming, September 1991, Why Use Lime, Pg 4.

Northland Fertiliser Co Limited. Northland Fertiliser seminar 10th.

O'Connor M.B, Foskett H.R, Smith A, 1981, The effect of a low rate of lime on North Island hill country pasture and animal production and the economics of use. Proceedings NZ Society of Animal Production: 41:82-87.

O'Connor M.B, Hunt B.J, 1996, Use of capital fertiliser and lime to improve pasture production in Northland. Proceedings of the New Zealand Grassland Association 57:139-144.

Roberts A.R.C, Edmeades D.C, 1993, The principles and practice of soil fertility and fertiliser use on dairy farms: Waikato, Bay of Plenty, Taranaki. AgResearch, Ruakura Soils and Fertiliser Group. Dairying Research Corporation Ltd.

Rowell D.L, 1994, Soil science methods and applications. Department of Soil Science, University of Reading.

Schutte K.H, 1964, The biology of the trace elements - their role in nutrition, International monographs: Aspects of animal and human nutrition.

Swallfield P.W, 1970, The grasslands revolution of New Zealand.
Thomsen N.A, 1981, Lime and dairy production. Proceedings NZ Grassland Association:

43:93-103.

Toxopeus M.R.J, 1989, Lime reponses in sheep grazing pastures on yellow - brown loams on the northern King Country, North Island, New Zealand. NZ Journal Agricultural Research: 32:81-94.

United Nations Economic Commission for Europe, 1983, Efficient use of fertilisers in agriculture, developments in plant and soil sciences Vol 10.