PRINCIPLES OF SUSTAINABLE AGRICULTURE

MONITORING AND MANAGING ACID SOILS

Department of Agriculture

National Soil Conservation Program

The year 1990 was the Year of Landcare and the beginning of the Decade of Landcare, with its focus on soil degradation.

As part of this initiative, the Federal government, through the National Soil Conservation Program (NSCP), is supporting this booklet, the fifth in a series outlining the principles of rational and sustainable agriculture.

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PRINCIPLES OF SUSTAINABLE AGRICULTURE

5. MONITORING AND MANAGING ACID SOILS

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FOREWORD

By the Hon Bill McGrath, Victorian Minister for Agriculture

Soil acidification is a hidden problem costing Australian farmers around $300 million in lost crop and pasture production each year.

In Victoria, one third of agricultural soil is naturally acidic and productivity of more than five million hectares is, thereby, threatened.

It is estimated that soil acidity may limit agricultural production on more than 14 million hectares in southern Australia where rainfall exceeds 500 mm annually. Certain farming and pastoral systems have, in addition, accelerated the acidification of soil to the point where plant growth is restricted. Soils causing most concern are those in Victoria's cropping zone and non-arable grazing country in the eastern and southern areas of the state.

Soils degraded by acidification are not sustainable. Farmers on such land will have increasingly fewer options in the types of plants they can grow.

Managing acid soils is complex from both a scientific and an economic viewpoint. In the short term farmers may see no benefits in preventing acidification, however, inaction will lead to further acidification which is more difficult to treat in the long term.

This booklet looks at the nature of the acid soil problem and provides practical information on how to identify, monitor and manage acid soils.

MONITORING AND MANAGING ACID SOILS

INTRODUCTION

Soil acidification is a hidden problem costing Australian farmers about $300 million in lost crop and pasture production each year. In Victoria, about one third of the agricultural soil is naturally acid - three million hectares are strongly acidic. This booklet discusses the nature of the acid soil problem and provides information on how to identify, monitor and manage acid soils.

SOIL ACIDITY AND ACIDIFICATION

Soil acidity describes the current pH or acid status of a soil. The pH of a soil is a measure of its acidity or alkalinity. An acid soil has a pH of less than 7 measured in water (alkaline soils have pH above 7). Soil acidification is the process of change over time. It is a natural process which occurs as soils age, are broken down by weathering, and undergo loss of nutrients through leaching. The extent and depth of acid soil is dependent on the soil parent material as well as the continuous weathering and leaching processes. Agricultural farming practices can accelerate the soil acidification processes.

Soil acidification is a major problem in several ways.

- It causes a loss of productive land, reducing crop and pasture yields.
- It is difficult to recognise
- Treatment is expensive.
- If not managed properly acidification may extend to the subsoil where currently treatment is impractical and expensive.
- If vegetation cover is reduced as a result of soil acidity, the risk of soil erosion is increased.

Scenic but Acidic - Granite soils of N.E. Vic

Where rainfall is over 750 mm/year (30 inches) most soils are naturally acid.

The pH status of the soil can directly affect plant production together with associated soil nutritional and microbiological changes that are responsible for the changes in plant growth. Acid soils should not be treated in isolation from more commonly known nutritional problems, but should be managed in conjunction with an overall soil fertility program. Poor growth on strongly acid soils does not necessarily mean that soil acidity is the main factor limiting production as low phosphorus levels are often the major barrier to increased production. Applying lime will not correct a phosphorus deficiency. Phosphorus applications are still required when lime is used.

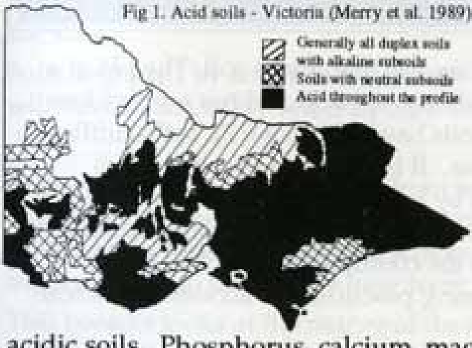


Fig 1. Acid soils - Victoria (Merry et al. 1989)

In strongly acid soils nutritional deficiencies or excesses can limit the production of a wide range of agriculturally important plants. These limitations are collectively known as acid soil infertility. Elements such as aluminium and manganese can increase to toxic levels to plants growing in strongly acidic soils. Phosphorus, calcium, magnesium and molybdenum commonly become less available. The establishment, survival and performance of rhizobia bacteria may also be affected in strongly acidic soils.

As soils acidify, aluminium is released from clay minerals and becomes increasingly available to plants. Aluminium is toxic to micro organisms and plants and as a result abnormal plant root development can occur.

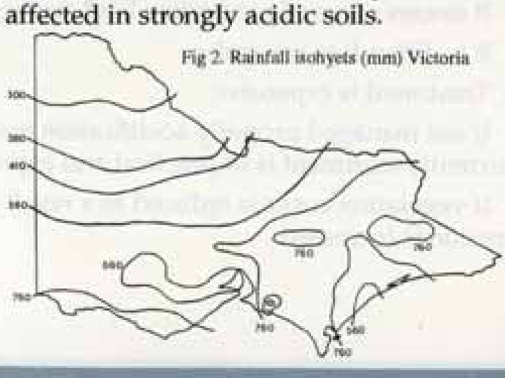


Fig 2. Rainfall isohyets (mm) Victoria

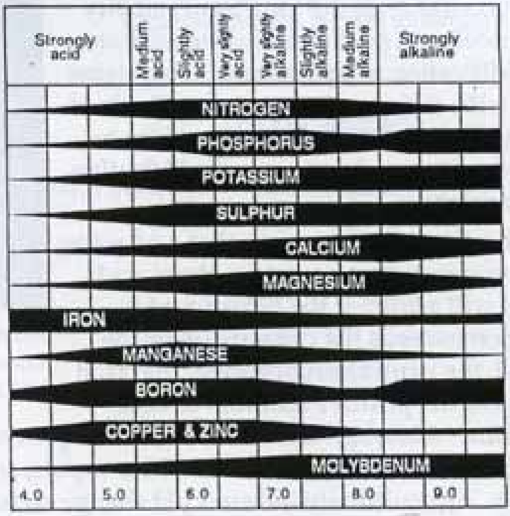
result abnormal plant root development can occur. Availability of aluminium in the soil can also prevent plants taking up valuable phosphorus, and cause trace element problems such as molybdenum deficiency. Manganese, toxic to plants in large concentrations, also becomes increasingly available to plants, particularly under conditions of waterlogging.

Short, stubby ineffective roots characteristic of aluminium toxicity in acid soils.

Prevention of acidification is probably not practical but changes in agricultural practices can alter the rate of acidification and addition of lime may be used to raise the soil pH to improve farm productivity. Soil acidification not only occurs in the topsoil, but in some cases, extends into the subsoil and may affect the productivity of deep rooted plant species such as phalaris and lucerne.

Unfortunately, there is no quick-fix method to correct acidic subsoil and as a result, this poses a major threat to sustainable production in some areas.

Lime is currently the best management option to ameliorate acid soils.



How pH affects nutrient availability

Ground limestone, the most common liming material, has the following effects:

- raises soil pH
- increases the availability of calcium and molybdenum
- decreases the toxic levels of aluminium or manganese
- enhances nodulation of many temperate legumes

As lime moves slowly down the soil profile (less than one cm/yr), mechanical incorporation achieves the fastest results. However, the use of surface applied lime, lime banding and deep placement of lime have all been demonstrated to be useful and may have important but restricted applications.

Low plant nutrients (especially phosphorus), aluminium and manganese toxicities are common constraints to crop and pasture production on most acid soils in southern Australia.

A top-dressing of lime is the best immediate solution for widespread soil acidity

Soil acidification is an important factor when considering the long term stability of agricultural production systems. Rates of acidification to agricultural ecosystems vary with different forms and methods of production and with the soil's ability to buffer against a change in soil pH (buffering capacity).

In soils, there are processes that add acids and processes that neutralise these acids. A soil will acidify if the rate of acid addition exceeds the capacity of, or the rate of, the neutralising process; that is, if there is a net positive addition of acid over time. Although farmers can grow improved pastures and crops on naturally acid soils with minimal lime inputs, soils will continue to slowly acidify. Agriculturally induced pH change on naturally acid soils of one unit may occur after tens, or hundreds of years depending upon the geological origin of the soil. A stable agricultural ecosystem demands soil management practices that slow soil acidification.

The development of subterranean clover based pastures on naturally acid and mildly acid soils has relied strongly on the correction of a range of nutrient deficiencies. The use of phosphorus, sulphur and molybdenum fertilisers, along with plant species tolerant of acid soils, and low cost means of establishing nodulated legumes, (inoculation with effective rhizobia strains, lime pelleting or banding lime with the seed) has promoted the growth of improved pastures on the more acid soils.

Poor nodulation results in stunted clover growth

Much of the acidification of soils has been incorrectly blamed on the use of superphosphate. The major cause of acidification of soils under pasture in south eastern Australia has been the growth of legumes and associated build up of soil organic matter and nitrogen. Superphosphate increases legume growth which indirectly

Nitrogen Fertilisers

Mono-ammonium phosphate (MAP)
Sulphate of ammonia
Di-ammonium phophate (DAP)
Anhydrous Ammonia

Urea

Ammonium nitrate
Superphophate
Potassium fertiliser
Potassium Chloride

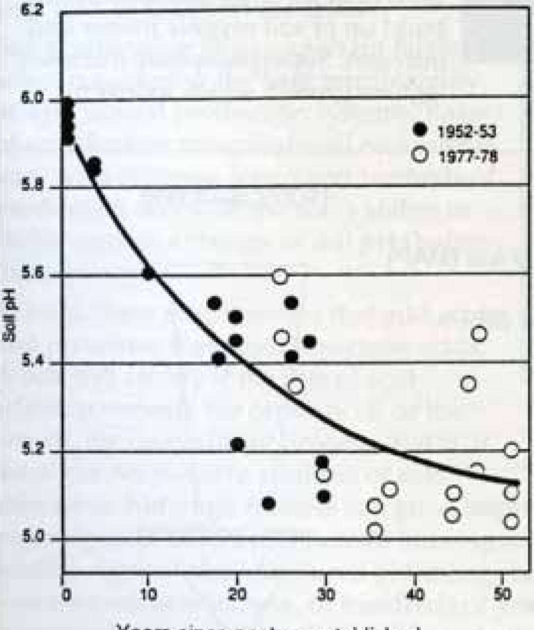
Effects of different fertilisers on soil acidity

affects soil acidification. Nitrogen fertilisers may also contribute to soil acidification, however, different fertilisers have varying effects on soil acidity.

IDENTIFYING ACIDITY

Unlike salinity, erosion, overstocking or rabbits, soil acidification is a slow and much less visible form of land degradation. Production will not crash overnight, but will be a gradual and often subtle process.

RELATIONSHIP BETWEEN AGE OF SUBTERRANEAN CLOVER PASTURE AND pH (1:5 WATER) OF THE SURFACE 10cm OF SOIL



Source: Williams (1980)

Although the potential for soil acidification under improved pastures was reported in the 1950s, it is only over the last two decades that pH has declined to the extent that plant productivity of sensitive species is affected.

For example, in north-eastern Victoria, the first signs were noticed 10-15 years ago when farmers began to report that the newer cultivars of phalaris (Sirosa and Sirolan) did not persist past the first few years. A major reason for this was that the soils had become more acid over the last 30 years, and have now acidified to the point where aluminium toxicity limits phalaris persistence (including the cultivar, Australian).

Subsoil acidification means that the deep root system of phalaris cannot develop due to toxic aluminium stunting root growth. Cocksfoot is more tolerant to aluminium toxicity than phalaris, hence it performs better in these soils.

Acid sensitive plants, such as barley and canola, may indicate acidic conditions by failing to establish. Typically, the crop may have clearly visible yellow patches. Another sign is poor establishment of phalaris and lucerne. If the soils in a district are naturally acid, most of the crops and pastures that grow well in that district will be acid-tolerant.

Evidence of soil acidification is usually taken from relative measures of soil pH between comparative treatments in long-term experiments, or from survey data contrasting developed and undeveloped soils. Some soils in north-eastern Victoria have been shown to have decreased by up to 1 pH unit over 40 years. The type of crop and rotation is important in determining the degree of acidification. For example, at Rutherglen a pH decline of 1 unit was observed over a 15 year field trial in which lupins were grown continuously compared with continuous wheat. In a recent statewide survey of surface (0-20cm) soils on the permanent pasture regions of Victoria it was found that acidification had occurred where pastures were dominated by annual or annual legume/perennial grass mixtures.

Apart from keen observation on long term paddock performance, soil testing is the only way to determine the severity of soil acidity. A soil test result below pH calcium chloride 4.5 (or pH water 5.3) is a warning that production may be affected. Soil testing for aluminium should be the next step to determine whether aluminium toxicity may be reducing production. It is advisable to consult a specialist with local knowledge to help with interpretation of soil test results as often the laboratory report alone will not be sufficient or may be misleading as to whether soil acidity is the major limitation to production.

It is important to sample correctly. To be confident your sample of the surface soil (0-10cm) or subsoil represents the whole paddock, collect and thoroughly mix at least 30 samples. It may be easiest to walk a "W" across the paddock collecting samples as you go. Avoid areas such as stock camps, fence lines and under trees. Send your soil sample (about a cup from the mixed sample) to the laboratory as soon as possible.

Symptoms of crops and pastures affected by soil acidity include:

- Poor persistence of phalaris, - plants pale and lacking vigour.
- Few nodules on legumes as the rhizobium bacteria does not thrive in acidic conditions.
- Abnormal and stunted root development (may be due to aluminium toxicity).

- Poor establishment of legumes after cropping or cultivation.
- Slow growth and lack of plant vigour.
- Patchy crop growth.
- Decline in crop yield.
- Pale or red discolouration on leaves (particularly clover).
- Decline in the number of soil organisms such as earthworms.
- Increase in volunteer weed species, for example, sorrel.

Soil acidity is a fertility problem and should really be thought about in much the same way as we do for potash or superphosphate applications. Farming operations remove, or cause the loss of varying amounts of nutrients such as calcium, magnesium and potassium which, if not replaced by fertilisers, are naturally replaced in the soil by hydrogen. Soil pH is the measure of the hydrogen ion activity in the soil.

Poor nodulation and ineffective root growth can indicate acidity problems

Without appropriate rhizobia strains subterranean clover growth may be retarded in acidic soils.

Among the major soils used for permanent pasture and pasture ley farming, there are many with surface profiles that are moderately to strongly acidic (less than pH calcium chloride 4.5) These soils are sufficiently acid to limit the growth of some acid sensitive crop and pasture species such as lucerne, barley and some wheat varieties. Other soils in the mildly acid category (pH calcium chloride 5.5 to 6.5), may become more acid over a period of agricultural production to join the problem soil group.

Without lime application soil acidification has been measured in a number of pasture and cropping soils, particularly in north eastern Victoria. The surface horizons of some weakly buffered soils (such as sandy soils), have been acidified .

Research at the State Chemistry Laboratory has identified indicators of land susceptibility to acidification.

These include:

- soils which have light texture (sands to sandy loams with low clay content).
- soils which have low organic matter content (less organic matter reduces the pH buffering capacity of the soil).
- soils which are moderately or slightly acid (pH in CaCl2 > 4.5).
- soils from areas which experience dry summers.
- agricultural systems where an annual legume is a major component in the plant composition (for example, sub-clover in annual pastures).
- agricultural systems where nitrogenous fertilisers with ammonium salts are used.

CAUSES OF SOIL ACIDIFICATION

Soil acidification is a long-term, continuous process which has accelerated under current agricultural systems. Soil acidification due to the long-term use of subterranean clover pastures is well documented in parts of the high rainfall areas of southern Australia exhibiting the indicators listed below. Existing agricultural production systems have been shown to accelerate acidification of the soil compared with native ecosystems.

The major processes responsible for soil acidification are increased soil organic matter, nitrate leaching and removal of animal products, or transfer of plant products to stock camp areas through dung and urine.

Acidification, which represents the addition of acid components, mainly occurs from carbon and nitrogen cycle processes. Nitrogen cycle processes are dominated by leaching of nitrate. In the carbon cycle, acids are produced in association with increases in soil organic matter, with the removal of plant and animal products, and with the transfer of dung and urine to stock camp areas of paddocks.

Researchers have estimated that carbon cycle acids account for 40-50 percent of the acids added to soils under fertilised annual and phalaris pastures. Organic matter accumulation, transfer of dung to stock camps and hay removal contributed the most acid while animal, meat and wool product removal and urine transfer contributed very little. In the nitrogen cycle, acid is produced when nitrate is formed following nitrogen fixation by legumes (nitrification), and is then lost by leaching or runoff. Subsequent conversion of the organic nitrogen to nitrate ion (mineralisation) may occur during periods of low plant demand for nitrogen,and the nitrate ion is lost from the soil due to leaching. This process acidifies the profile and the extent of acidification is related to the number of years that the land has been growing legume based pastures.

The change from native deep rooted summer-autumn active perennial grasses to shallow rooted annual legumes is the major imbalance in the nitrogen cycle contributing to acidification.

Soils which are moderately or slightly acidic are more susceptible to rapid pH decline than soils which are strongly acidic. Most cropping and horticulture production in Victoria is on soils which may be susceptible to acidification.

In pastures, acidification has been found in systems supporting sub-clover yet acidification has not been evident in perennial pastures. CSIRO studies have shown a relationship between major soil groups and the risk of acidification. In regions receiving less than 450 mm annual rainfall, such as the north-west region of Victoria, no acidification has been found. Nineteen years of pH data for pasture soil in the Heytesbury and Hamilton district revealed slight declines over time of 0.1 to 0.2 of a pH unit.

Factors associated with acidification of soils are:

Rainfall: Soils in high rainfall areas are naturally more acid due to more leaching of nutrients. Rainfall has an important effect on the rate of soil acidification as it influences plant productivity (including the amount of nitrogen fixed by legumes) and leaching.

Soil properties: Soil texture and initial soil pH have an effect on soil pH decline with clay soils having a greater ability than sandy soils to resist (or buffer against) pH change. As a result, greater acidification rates have been measured in sandy soils under agriculture than in clay soils over a similar time period. Only a small decline in pH has been measured in soils that were naturally strongly acidic prior to agriculture. However, when the soil pH is high, a larger pH decline has been measured. In acid soils, acidification may still be continuing even though it cannot be measured by pH change, due mainly to a depletion of nutrients in product removal and nitrate leaching.

Soils most prone to acidification are the lightly textured, sandy soils in high rainfall areas

Leaching of nitrogen:

Nitrogen initially fixed by legumes and later lost by leaching, is associated with acidification. In the nitrogen cycle, organic nitrogen (mostly plant protein in plant residues) is converted to ammonium, which is then converted to nitrate. This results in one hydrogen ion being released for each nitrate generated. If this nitrate is taken up by plants, the soil remains neutral, however, if the nitrate is leached through the soil, it can take with it calcium, magnesium and potassium and leaves the free hydrogen ions that were produced to accumulate in the soil. The more hydrogen ions, the more acid the soil becomes.

Variation in soil acidification rates on different soils can be attributed to the time period involved and the particular farm management system, initial soil pH and buffering capacity (soil's capacity to resist decline in pH as acid is added) and the amount of acid consumed by dissolving soil minerals.

Sandy soils, normally low in organic matter have a poor buffering capacity, while clay soils high in organic matter need more acid to reduce the pH and conversely, more lime to reverse the effect. Outside the range 4.5-7.5 the soil pH is often very strongly buffered by reactions involving carbonate minerals (at high pH) and aluminium hydrous oxides (at low pH).

As the pH falls below 5.0 (water), aluminium and manganese dissolve faster. In agricultural systems it is difficult to obtain pH values below about 3.9 because at that level, clay minerals and oxides dissolve fast enough to neutralise all the acid being added. However, at this soil pH mineral dissolution processes will cause serious irreversible soil degradation.

UNDERSTANDING SOIL pH

Soil pH is probably the most frequent measurement made on soils. It is a measure of the chemical activity of hydrogen ions in the soil expressing acidity or alkalinity. It is also a guide to the need for lime, the likely occurrence of nutrient deficiencies and toxicities, and activity in the soil of microbiological processes. Soil pH can be regarded as both a symptom of soil condition and a cause of many chemical reactions that occur in soils.

The pH value is the negative logarithm of the hydrogen ion activity of a specified soil solution and is given by the formula:

$$pH = -\log10[H+]$$

Each shift of one unit on the pH scale is a ten-fold change in alkalinity or acidity. For example, pH 5.5 is ten times more acidic than pH 6.5, and pH 4.5 is 100 times more acidic than pH 6.5.

The degree of soil acidity and alkalinity is usually expressed in terms of pH of a soil suspension. The simplest definition of an acid soil is one that has a pH less than 7 measured in water. Neutral to slightly acid soils favour the availability of major nutrients but in strongly acid soils (less than pH 5.5) the availability of major nutrients such as nitrogen, phosphorus, calcium, magnesium and molybdenum decreases while the availability of manganese and aluminium increases.

A major factor influencing laboratory soil pH tests is the measurement of electrolyte activity of the liquid in which the soil is suspended. Some laboratories use a suspension of 0.01M calcium chloride to test pH levels, however as the electrolyte activity increases the pH of the suspension decreases, which affects pH readings. Other laboratories use a water suspension which usually gives a higher pH reading. Therefore, before interpreting soil pH results, it is important to know which method of analysis has been used.

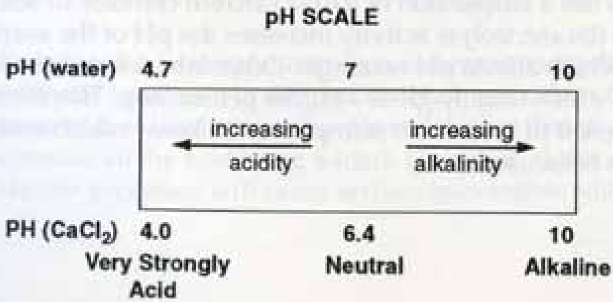
Soil pH measured in calcium chloride is now the preferred measurement with research showing this method giving a more consistent reading. The pH values of soils suspended in dilute calcium chloride solutions fluctuate less over time than the pH values of the same soil suspended in water.

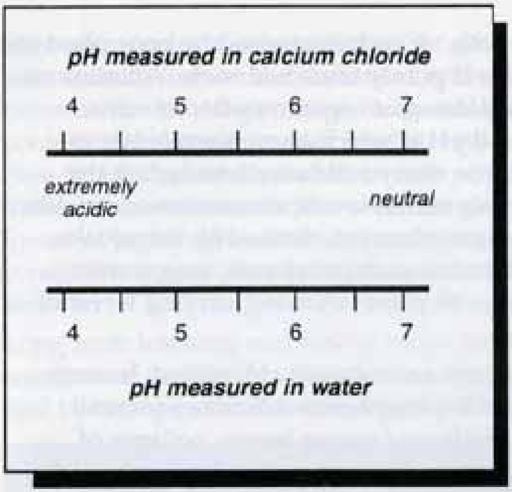
There are spatial and seasonal variations in soil pH in the field and many of these can be explained by the effect of electrolyte concentration of the soil solution on pH. Factors which alter electrolyte concentration, e.g. fertiliser addition, leaching, microbial activity and soil moisture, will also affect soil pH.

Colorimetric kits using Raupach's indicator are available for measuring soil pH in the field. This method uses a pH sensitive indicator solution and white, powdered barium sulphate to absorb the colour. It commonly gives pH values plus or minus 0.5 of a pH unit to those measured in the laboratory in 1:5 suspensions in water.

The pH (calcium chloride) readings are usually lower (by about 0.7 to 1.0 units) than pH (water) readings.

Soil testing laboratories will usually do both pH measurements. A strongly acid soil has a pH (calcium chloride) of less than 4.5 rarely falling below 3.8-4.0. The lower the soil pH the more likely it is that other soil nutritional or biological factors may be affecting production.





A soil with a pH (calcium chloride) of 4.3 - indicating problems for sub clover - may have a pH (water) of 4.9 or lower, or a pH (water) of 5.3 or higher.

pH (calcium chloride) is a more reliable indicator of soil acidity than pH (water).

CHEMISTRY OF ACID SOILS

Plants grown in acid soils exhibit many physiological disorders related to changes in the chemical forms of mineral elements. The higher rainfall common to acid soils often leaches essential mineral elements from the soil and may provide toxic conditions by increasing the solubility and activity of other elements.

Two basic factors limit the fertility of acid soils: poor nutrient status (for example phosphorous, sulphur, calcium, magnesium deficiencies) and toxic levels of some elements (such as aluminium and manganese). On most soils plants can achieve near-maximum growth rates within the pH range (water 1:5) 5.0 to 7.0. Toxicities and deficiencies induced by pH effects on nutrient availability are generally critical only outside this range.

Major Toxic Elements In Acid Soils

* *Aluminium (Al)*

Aluminium toxicity is probably the most important growth-limiting factor for plants in most strongly acid soils. It is characterised by poor plant root development including shallow and poorly branched roots. Aluminium toxicity also limits microbial breakdown of organic matter in some strongly acid soils. The critical soil pH at which aluminium becomes soluble or exchangeable depends on many soil factors, including the predominant clay minerals, organic matter levels, concentrations of other cations, anions and total salts. Aluminium interferes with the uptake, transport and use of essential elements such as calcium, magnesium, phosphorus, potassium and iron with plants showing varying levels of tolerance.

The symptoms of aluminium toxicity are not easily identified. In some plants the foliar symptoms resemble phosphorus deficiency (overall stunting) or calcium deficiency (curling of young leaves, collapse of petioles). Aluminium toxicity is not readily detected in the field while the surface remains moist, but may become evident during dry periods when plants depend on the ability of their roots to penetrate the subsoil in search of moisture reserves.

In general, it has been found that at a pH of 4.8 ($CaCl_2$) (pH 5.8 water) and above, concentrations of aluminium are below plant toxic levels.

There are two methods used to measure aluminium in the soil. The most sensitive method estimates the concentration of aluminium in the soil solution, which is encountered by the plant root. This is the aluminium concentration in 0.01M $CaCl_2$ extract which measures the amount of aluminium removed in a 1:5 soil to water calcium chloride suspension (as used to measure pH). This is the aluminium immediately available to the plant. The same technique can be use to measure manganese levels. Total exchangeable aluminium is measured by some laboratories using 1.0M potassium chloride (KCl) extracts and estimates the total aluminium that may become available to plant roots. There is no direct relationship between the two methods except that 1M KCl aluminium is about five to ten times higher than 0.01M $CaCl_2$ aluminium.

* *Manganese (Mn)*

Manganese toxicity is probably the second most important growth limiting factor in acid soils.

However, under some conditions, or with particular plant species, manganese toxicity may be the dominant acid soil problem. Solubility and potential toxicity depends on many soil properties, including manganese content, pH, organic matter level, aeration and microbial activity. Manganese toxicity generally occurs in soils with pH water values of 5.5 or below if the soil contains sufficient total manganese. However, it can also be found at higher pH values in poorly drained or compacted soils where conditions favour the production of divalent manganese that plants absorb.

Long term leaching and liming may also result in very low levels of manganese in soils. Manganese toxicity is frequently induced or intensified by nitrogen fertilisation, which lowers soil pH. The addition of organic matter can reduce manganese toxicity as it is closely related to the activities of micro organisms.

Canola grown on poorly drained acid soil showing symptoms of toxic levels of manganese

Unlike aluminium, excess manganese appears to affect plant tops more directly than roots. Plant symptoms of manganese toxicity such as short-term bright yellow leaves of canola under waterlogged conditions are often detectable at stress levels that produce little or no reduction in vegetative growth. In contrast, aluminium toxicity can reduce yields without producing clearly identifiable symptoms in plant tops. The interaction of manganese with many other mineral elements may under certain conditions alleviate manganese toxicity.

Levels of available manganese are at their lowest in winter and increase in the spring. This seasonal variation prevents reliable predictions of the effects of manganese.

Major Nutrient Deficiencies on Acid Soils

* *Calcium (Ca)*

Calcium deficiency in plant tops shows up as marginal chlorosis (abnormal yellowing of plants). Most soils contain an adequate supply of calcium. Where there is a deficiency, it is seen first in parts of the plant that are furtherest from the main flow of water within the plant.

The effects of aluminium toxicity and calcium deficiency in acid soils are often difficult to tell apart. However in many acid soils there is enough calcium for good plant growth so it seems valid to conclude that it is excess aluminium interfering with calcium uptake rather than absolute calcium deficiency that is the cause of poor plant growth. On strongly acid soils however, the increase in exchangeable aluminium and manganese will compete with calcium and magnesium on the exchange sites of the clay surfaces, such that calcium availability may be limiting.

* *Magnesium (Mg)*

Magnesium deficiency decreases vegetative growth, delays the onset of flowering and affects the accumulation of other mineral elements in leaves and roots.

Magnesium deficiencies first appear in the older tissues and leaves. Initial and moderate symptoms are characterised by light colouring (loss of chlorophyll) between leaf veins. Severe deficiency results in dark, dead patches between veins, and reddish purple leaves. In acid soils, decreased magnesium uptake in plants is not attributed to low pH itself but to an interaction between aluminium and manganese.

* *Molybdenum (Mo)*

Most soils are low in molybdenum and its availability diminishes with decreasing pH. Deficiency symptoms are similar to those of nitrogen. Legumes typically show pale green to yellow leaves. They have a higher requirement for molybdenum than grasses and cereals, and usually exhibit deficiency symptoms first. Crops and pastures grown on naturally acid soils will often exhibit deficiency even though molybdenum is only required in trace amounts.

Soil Acidity and Phosphorus

Soil acidification affects phosphorus availability, by increasing aluminium levels in the soil which reduces plant phosphorus uptake. Aluminium immobilises phosphorus in the soil and the plant, causing symptoms similar to those of phosphorous deficiency. Variable results have been obtained for phosphorus availability in response to lime application.

In many acid soils phosphorus is concentrated at the surface, while high concentrations of toxic aluminium are found only at depth. Crops and pastures growing on such soils are therefore exposed to phosphorus and aluminium at different depths in the soil profile. In most soils additional phosphorus in fertiliser applied to the surface will interact little with aluminium in the subsurface.

Many acid soils are so grossly infertile that an appropriate fertiliser program is needed together with lime to achieve any growth responses. Applying lime will not correct a phosphorus deficiency. Normal phosphorus applications are still required when lime is used.

In some cases the effect of soil pH on disease incidence should be considered when managing acidity. Diseases can be suppressed and stimulated by acidity. Take-all in wheat is an example where disease incidence increases with increases in pH (calcium chloride) above about 5.0.

Lime and appropriate inoculum boosts subterranean clover growth on acidic soils

Removal of product

Grain, pasture and animal products are slightly alkaline and their removal from a paddock leaves the soil slightly more acid. Rates of acidification are modified by the use of fertiliser and by variations in climate.

The acidifying effect of farm produce removal is shown in Table 1 (Slattery et al., 1991). Table 1 shows for example that hay (or silage) production per hectare is far more acidifying than wool or meat production. The values of lime required have been calculated using several assumptions.

Table 1 : Lime required to balance the acidifying effect of farm production (Slattery et al. 1991)

Farm produce	(kg lime/t product)	Yeild or stocking rate	kg lime/ha
Lucerne hay	60	4 t/ha	240
Grass hay	30	4 t/ha	120
Wheat	9	2 t/ha	18
Lupins	20	1 t/ha	20
Wool*	14	10 dse/ha, 6 kg/wool sheep	1*
Meat*	171	0 dse/ha	6*
Milk*	4	0.6 cows/ha, 3,200 Litres/cow/year	8*

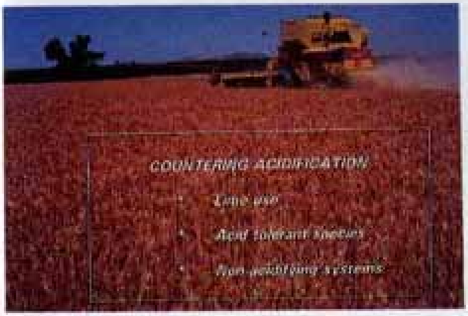
* The transfer of animal waste acidifies the majority of the paddock particularly where paddocks are set stocked as this allows stock camp areas to develop. Grazing "costs" 23 kg lime/ha year at a stocking rate of 10 dse/ha.

If farm production and fertility is known, and acidification due to leaching of nitrate can be estimated (probably between 25-100 kg lime/ha/year) acidification rates of various farm enterprises can be calculated. The more intensive the farming system, the greater the rate of acidification.

Options to manage soil acidity

Applying lime (incorporating if possible) is the most practical way to reverse soil acidification. However, acidification can be slowed by changing some farming practices. Use of tolerant species and varieties may allow a paddock with acid soils to remain productive however, their use will slow but not prevent acidification. Eventually growth and yield of even the most tolerant species will decline unless lime is applied.

Maintaining production on acid soils should be viewed as a long term management strategy. It is now recognised that agricultural practices contribute to soil acidification and that increasing acidity will gradually reduce plant production through its effect on soil fertility and biological activity. If the subsoil becomes acid then agricultural production may be restricted for years, if not permanently.



Farmers have three main management options:

- apply lime (incorporate when sowing or topdress).
- grow acid tolerant species.
- adopt less acidifying farming systems and practices to slow acidification.

LIME

Application of lime is the most practical way to neutralise soil acidity. The lime rate required to regain the yield potential on an acidified soil may vary from 1 to 6 tonnes per hectare. High rates of lime are required when large changes in soil pH are desired, or when the soil has a high pH buffering capacity.

While lime application will restore soil pH to a suitable level to grow plants that are sensitive to acidity profitability, it will not however prevent acidification. The pH of the limed soils after many years may revert to its previous acidic status because of the continuous acidification. This phenomenon is more critical for soils which are poorly buffered.

The most common application rate is 2.5 t/ha. For cropping country the time of application normally fits into the crop and pasture rotation, that will give the best return. Applying lime to obtain a pH ($CaCl_2$) greater than 5 cures most soil acidity problems. The amount of lime depends on the pH change required, soil buffering capacity and the depth to which the lime is incorporated.

Lime can neutralise existing surface acidity and prevent future subsurface acidity

Pasture and some crop yield responses to lime are unpredictable, partly because of their sensitivity to toxicity or deficiency factors and the infertility of acid soils.

Lime requirement has been defined as either the amount of lime required to raise the soil pH to a certain value, or, in view of the role of aluminium and manganese toxicities in acid soils, the amount of lime required to prevent these toxicities. The amount of lime required also depends on the properties of the lime, and the extent of mixing. Liming works because it precipitates and thus eliminates aluminium toxicity. It also improves soil structure, nodulation and alters nutrients imbalances. In acid surface soils, the precipitated aluminium represents a buffering reserve of potentially reactive aluminium that is not exchangeable but will react with lime.

In arable situations lime is mixed to the normal ploughing depth, but in non-arable systems such as perennial pastures or

Experimental plots in north-eastern Victoria ripped and limed at 2.5t/ha.

hill country it may be applied to the soil surface. In the short term, topdressed lime is often ineffective on surface acidity due to the slow movement of lime in most soils.

The addition of lime to an acidic soil produces a more favourable environment for plant growth

In these cases root growth is frequently confined to the improved topsoil because the toxicities of the subsoil strongly restrict root extension and growth. Liming of subsoils is costly and requires specialised equipment.

In temperate annual pasture systems based on legumes, the lime (calcium C03) required to balance soil acidification is estimated to be 150-250 kg lime/ha/yr. For perennial pasture in areas dominated by summer rainfall,the rate of acidification is estimated to be much lower (less than 50 kg lime/ha/yr to balance acidification) due to lower amounts of nitrate leaching.

Lime can be applied either as maintenance dressings on a regular basis, or as a large amount every 10-20 years. It will be cheaper to develop a lime program where a large dose is applied to a small part of the farm in any one year, than applying small maintenance dressings over all paddocks every year. The amount of lime used should at least equal the estimated amount that the paddock needs, based on past production and

Liming trials at Rutherglen Research Institute using canola also considering the time frame for reapplication.

Lime movement through the soil, for practical purposes, is nil. At commonly applied rates (2.5 t lime/ha) lime movement would be less than half a centimetre depth per year hence topdressed lime may have little effect for many years. Incorporating lime to a depth of 10 cm prior to sowing or topdressing several years before sowing is preferable.

For the quickest and maximum effect lime should be evenly spread and incorporated into the soil. Most lime is spread by contractors due to the need for specialised equipment because of the nature of the product and large quantities applied. Combines and seeders cannot handle the quantity and fertilisers spreaders have proved unreliable. To reduce lime dust blowing away, many contractors use a shroud. Lime can also be wetted to eliminate fine dust clouds.

To improve the effectiveness of surface applied lime use a fine grade product and spread when there is ground cover to prevent drift. Direct drilling after spreading lime provides some incorporation. Lime and super can be banded with the seed using direct seeding techniques.

It may take years before the benefits of surface application is seen. A rapid response to surface applied lime is most likely to be caused by release of molybdenum or improved legume nodulation.

Lack of response to lime

Some farmers observe no response to lime application. Some likely reasons for this are:

- lack of information on current soil pH prior to application (eg; the pH ($CaCl_2$) was above 5).
- inappropriate soil sampling method or incorrect interpretation of soil test results.
- application to acid-tolerant plants.
- failure to leave an untreated area for comparison, or failure to measure yield (it is difficult to gauge yield responses visually).
- inappropriate lime rate to correct the problem or use of poor quality product with low effective neutralising value.
- other limiting factors such as soil structure or disease.

- acidic subsoil resulting in a partial response.
- method of application may delay results.
- seasonal conditions have prevented a response that may be evident in following years.

Availability of funds is often the most limiting factor to lime applications however, despite initial product cost, the residual effect of lime may spread its benefits over many years.

ACID TOLERANT SPECIES

The greatest practical problem for farmers with acid soils is that their cropping and pasture options narrow to a choice of plants that tolerate soil acidity. If the soil is strongly acid then yields of even the most tolerant species will decline.

Once the topsoil acidifies, the subsoil may be at risk of becoming more acid. It then becomes more profitable to grow acid tolerant species (e.g. cocksfoot, triticale) than acid sensitive species (e.g. phalaris, lucerne, wheat). (See Table 2 for tolerance to aluminium). Whilst profitability can be maintained for some years by growing acid tolerant species, eventually productivity will only be maintained by using lime.

Acid tolerant species should be viewed as an option for maintaining production to give a breathing space to deal with the longer term acidification problem. Tolerant species can help farmers manage acid soils by maintaining cash flow if liming cannot be done as required or by maintaining or increasing production on non-arable country. Tolerant species can help slow the rate of acidification with more efficient use of nitrate

Plants vary in tolerance to soil acidity. Lupins (very tolerant) and barley (very sensitive) growing on strongly acid soils nitrogen and soil moisture, particularly by replacing annual winter grasses with a vigorous, perennial grass that has some summer growth. However, growing tolerant species will not prevent acidification.

Table 2: Tolerance of agricultural species to aluminium

Sensitive	Lucerne, canola, barley
Moderately sensitive	Phalaris, wheat
Tolerant	Sub. clover, perennial ryegrass, white clover, oats, lupins
Highly tolerant	Cocksfoot, tall fescue, triticale.

Table 3 - Temperate crop tolerance to soil acidity

Tolerant to acidity	Intermediate tolerance	Intolerant acidity
cocksfoot	white clover	lucerne
oats (some cultivars)	sub clover	annual medics
cereal rye	red clover	barley
narrow-leaf lupins	wheat	phalaris (seedl'gs)
tall fescue	wheat	canola
tritcale (some)	phalaris	

Table 4 - Tolerance of wheat varieties to soil acidity

Variety	Tolerance
Mokoan	sensitive
Oxley	sensitive
Meering	Moderately sensitive
Millewa	Moderately sensitive
Olympic	Moderately sensitive
Matong	Very tolerant

FARM MANAGEMENT SYSTEMS

Some farm management systems are more acidifying than others. Reconsidering current farm management may identify sensible changes that will reduce acidification. Continuous hay cutting has an associated lime replacement cost. Feeding out hay on to your most acid paddocks over a number of years may help to slow soil acidification on those paddocks.

Table 5: Soil acidification - low and high risk enterprises

Low Risk	High Risk
Perennial pasture	Annual pasture or crop
Rotational grazing	Set Stocking
Grazing	Hay cutting
Cereals	Lupins
Early crop sowing	Late crop sowing

More efficient use of soil water and nitrate nitrogen is an important way to slow soil acidification. Nitrate nitrogen is the main form of nitrogen that is taken up by the plant. It is very soluble and easily leached.

If nitrate nitrogen is leached out of the root zone before the plant can take it up, or before it is converted to nitrogen gas, the soil is left a little more acid.

Nitrate nitrogen leaching occurs mainly in winter when soils are wet. Mineralisation of organic matter over summer produces high levels of nitrate nitrogen and with the onset of autumn rains this nitrate is leached through the soil profile. Summer growing perennial grasses reduce the accumulation of nitrate nitrogen.

The nitrate is taken up as it is formed. Perennial grasses also extract water and nitrate nitrogen more effectively than annual plants because of their deep roots.

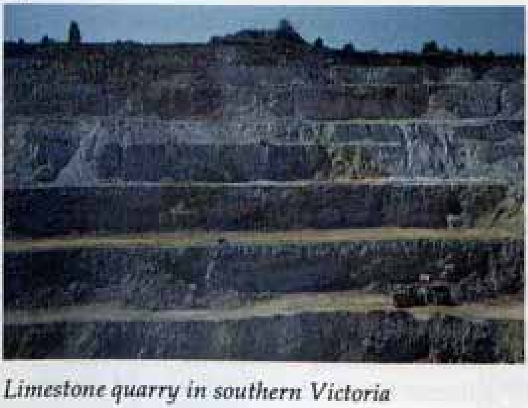
In acid soil cropping areas, pastures based on drought tolerant perennial species should be considered during the pasture phase of the rotation. Early sowing of crops will reduce nitrate leaching compared with late sowing. By sowing soon after the autumn break, the moisture and nitrate can be used before it moves further down the soil profile. Also split applications of nitrogen fertiliser to crops helps to minimise nitrate leaching.

However, even the least acidifying farming systems will eventually require lime to maintain soil pH and production.

LIME QUALITY

Lime is the general term for the products of limestone, a sedimentary rock made up mainly of calcium carbonate. Lime is used to neutralise acid soils and acts as a natural soil conditioner. Most of the effects lime has on plant growth are related to changes in soil pH or the amount of acidity. These include reducing toxic levels of aluminium and manganese, increasing availability of molybdenum and improving the nodulation of legumes.

There are three main types of lime available to alter soil acidity - agricultural lime, slaked lime and burnt lime. Agricultural lime is the most common form of lime used in agriculture. It comes from natural limestone that is mined and then crushed at a number of plants throughout eastern Australia. The quality (and therefore the effectiveness), of the different lime products vary. There are a few types of lime that are either mixtures of the types already mentioned, or by-products of industry. Dolomite is also a natural material containing a higher proportion of magnesium than agricultural lime.



Limestone quarry in southern Victoria

Assessing lime quality

The easiest way to compare lime products is to look at their chemical analysis. The effectiveness of a liming material depends on the purity of the lime and its ability to react with the soil. Pure calcium carbonate (limestone) is the standard against which all other liming products are measured. It has a neutralising value of 100.

The most important factors to consider when assessing a liming product are:

Capacity to neutralise soil acidity

The value of a liming product is related to its ability to neutralise soil acidity or its Effective Neutralising Value (ENV). This tells the buyer how much acidity a certain quality of lime will neutralise as compared with calcium carbonate. The calculation takes into account chemical analysis and the fineness of the product. Neutralising values can be higher than 100%, for example, pure calcium oxide has a neutralising value of 179. The higher the ENV, the greater the ability of the product to raise soil pH.

Industrial by-product is another source of lime

Calcium and magnesium content

Calcium and magnesium carbonate are the effective components of limestone. Where appreciable amounts of magnesium carbonate are present in the liming product, the neutralising value of the product may be greater than 100%.

Fineness

Neutralisation of soil acidity takes place close to the dissolving lime particles. The finer the particles in a liming product, the more quickly it will react with the soil. This is because the finer the particles, the greater the surface area exposed to react with acids in the soil.

Any sample of agricultural limestone will contain both coarse and fine material. It is the amount of fine particles in the sample that is important. The finer the product, the faster the result.

Moisture content

The moisture value reported indicates the amount of moisture present in the sample.

Choosing a liming product

The best way to compare liming materials is to consider the cost per unit of each product. This is calculated using a formula based on the product's ENV and the product's cost per tonne delivered and spread on the farm. Transport and spreading costs are the major components of the overall expense of applying lime.

$$\text{Unit cost} = \frac{\text{Total cost per tonne spread}}{\text{Effective neutralising value}}$$

The liming material that has the lowest figure based on this calculation is the cheapest product to spread on the paddock.

For example:

Lime can be purchased from two sources. Lime A has an ENV of 95 and costs $60/tonne spread, while Lime B has an ENV of 75 and costs $50/ tonne spread.

Lime A $\frac{60}{95}$ **= $0.63 per unit (of ENV)**

Lime B $\frac{50}{75}$ **= $0.66 per unit (of ENV)**

In this example, lime A is cheaper than lime B, based on costs in relation to its ability to neutralise soil acidity. This calculation can be made for any lime product. Price is not always the only consideration. Often equipment may not be available to adequately spread some of the very fine limes and a compromise may have to be made.

	A	B	C	D	E	F	G	H	I
Lime Company	Ca %	Ca Carb %	Mg Carb %	NV	Particle Size			Moist	ENV
					Coarse %	Medium %	Fine %		
A.C.I. Cal Lime	38.6	96.4	1.6	99.6	30.5	18.9	50.6	11.6	64.7
A.C.I. Mag Lime	23.9	59.7	36.4	103.6	10.2	9.3	80.5	5.1	90.2
A.C.I. Potash Lime	34.7	86.6	1.9	96.8	1.2	0.6	98.2	0.1	95.5
Blue Circle Flue Dust	31.7	79.3	1.9	96.8	4.4	8.1	87.5	0.1	83.4
Boggy Creek Lime	35.8	89.5	2.15	92.2	41.2	37.6	21.2	19.7	44.1
Brucknell Lime	32.8	82.0	1.94	85.5	49.3	18.2	32.5	16.7	41.3
Buchan Agri Lime	38.8	97.0	0.80	97.5	1.0	42.6	57.3	0.4	80.9
Calcimo Dried Lime	31.1	77.6	1.5	79.7	16.6	25.5	57.9	5.4	59.7
C.H.A. Agri Lime	37.3	93.1	25.3	128.8	22.9	22.2	54.9	0.1	90.8
Darriman Dry Lime	21.9	54.8	1.15	57.8	<0.1	<0.1	100.0	2.0	57.8
Darriman Agri Lime	26.5	66.2	1.3	68.1	32.2	17.9	49.8	11.3	43.4
Coopers Dolomite	13.1	32.8	29.18	69.00	51.9	21.8	26.3	N/A	30.8
Gillcar Ag Lime	35.2	88.00	1.94	91.4	13.7	18.2	68.1	20.4	73.5
Glencoe Lime	28.4	70.9	0.8	74	50.7	23.7	25.6	16.5	33.2
Kalmag Mineral F	21.9	54.7	27.4	88.2	23.4	18.9	57.7	N/A	62.9
Killambete Ag. Lime	28.4	71	2.22	75.3	43.9	21.3	34.8	11.5	39.1
Kurdeez Dry Lime	36.5	91.2	1.98	93.8	8.6	16.6	74.8	1.2	79.9
Kurdeez Undried	36.3	90.8	2.12	93.24	27.2	30.9	41.9	15.3	58.9
Lilydale Ag. Lime	32.7	81.8	11.5	94.3	1.7	43.6	54.7	0.2	76.4
Lilydale Burnt G.B.A.	50.5	126.1	22.2	154.5	20.2	22.3	57.5	0.1	144.8
New Lara Blend	28.9	72.8	3.44	80	30.9	22.9	26.2	6.2	50.5
Rentsch Sheen Lime	36.6	91.5	1.94	94.5	11.9	11.6	76.5	12.5	80
Saunders Lime	36.6	91.5	1.7	94.4	45.5	12.	42.5	N/A	51.2
Tucker Lime	29.6	74	0.3	76.8	36	29.1	34.9	N/A	43
Warrnambool Lime	32.7	81.8	7.6	90.6	1.0	57.7	41.9	0.1	69.4

All limes have been independently sampled by the Australian Fertilizer Services Association Inc. Committee to Combat Acid Soils and tested at the State Chemsitry Laboratory, Melbourne.

The Information is provided as a guide only as natural liming material can vary even from the same source.

Sorrel - favours an acid soil environment

Cocksfoot is a useful perennial pasture species tolerant of acid soils

GLOSSARY

Acid soil — An acid soil is a soil which has a pH of less than 7 in water. Generally, acid soils become a problem when the pH drops below 4.5 (measured in calcium chloride). The following specific problems may occur - aluminium toxicity, manganese toxicity, calcium deficiency and/or molybdenum deficiency.
Such problems adversely affect plant growth and root nodulation, which may result in a decline in plant cover and increase erosion hazard.

Acidity — The low pH (less than 7 measured in water) status of the soil.

Acidification — A combination of on going processes which render soil more acidic over a period of time.

Buffer capacity — The ability of a soil to resist a change in pH. The buffer ing action is due mainly to the properties of clay and fine organic matter. Thus, with the same pH level, more lime is required to neutralise a clay soil than a sandy soil, or a soil rich in organic matter, than one low in organic matter.

Leaching — The removal in solution of the more soluble minerals and salts by water seeping through a soil.

Lime — A naturally occurring calcareous material used to raise the pH of acid soils. The name is used to describe several liming materials, including agricultural lime and dolomite.

Nitrogen fixation	The assimilation of atmospheric nitrogen from the soil air by soil organisms to produce nitrogen compounds that eventually become available to plants.
pH	A measure of the acidity or alkalinity of a soil usually in 1:5 soil 0.01 M calcium chloride (CaCl2) suspension or a 1:5 soil water suspension. The CaCl2 measure gives lower pH values.
Soil ameliorant	A substance used to improve the chemical or physical qualities of the soil. For example, the addition of lime to the soil to increase pH to a desired level for plant growth, or the addition of gypsum to improve soil structure.

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