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NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Soil acidity and liming

Agfact AC.19, 3rd edition 2005

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NOTES ON PASTURE IMPROVEMENT

1. Pasture improvement may be associated with an increase in the incidence of certain livestock health disorders. Livestock and production losses from some disorders are possible. Management may need to be modified to minimise risk. Consult your veterinarian or adviser when planning pasture improvement.
2. Legislation covering conservation of native vegetation may regulate some pasture improvement practices where existing pasture contains native species. Inquire through your office of the Department of Infrastructure, Planning and Natural Resources for further details.

DISCLAIMER

The information contained in this publication is based on knowledge and understanding at the time of writing in March 2005. However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up-to-date and to check the currency of the information with the appropriate officer of NSW Department of Primary Industries or the user's independent adviser.

ACIDIC SOILS IN NSW

Acidic soils are an impediment to agricultural production. More than half of the intensively used agricultural land in NSW is affected by soil acidity. The gross value of agricultural production lost in NSW due to soil acidity has been estimated in the Land and Water Audit (2002) at $378 million per year. Ongoing acidification caused largely by normal agricultural practice increases limitations on future production and in some areas results in permanent degradation of soils in NSW.

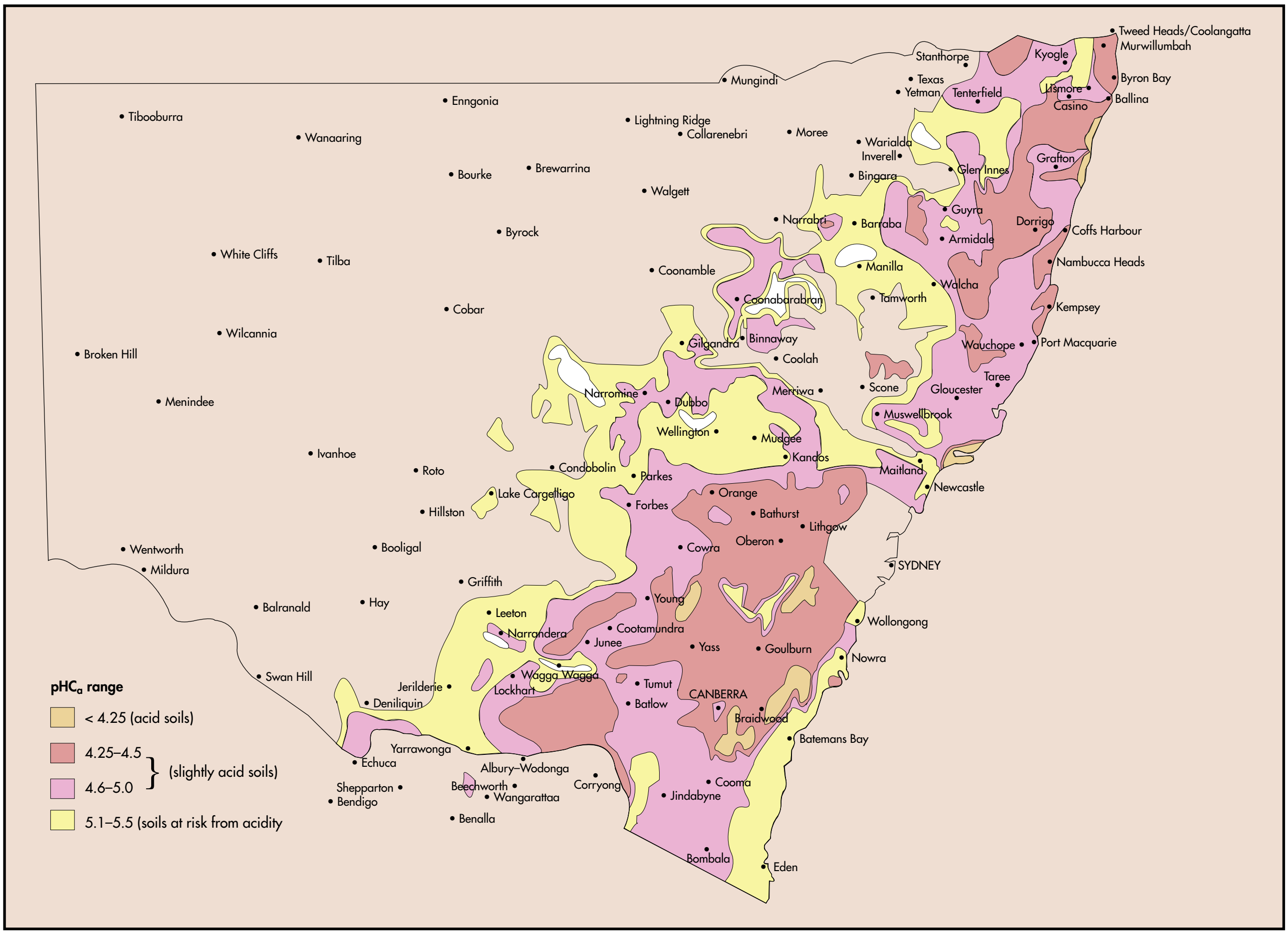
The average pH_{Ca}[1] of surface soil throughout eastern and central NSW based on data collected in 1989 is shown in Figure 1. It can be seen that large areas of the northern, central and southern tablelands, the central and northern coast, and the central and southern slopes have soil with a pH_{Ca} of 5.0 or less.

At that time it was estimated that 13.7 million hectares of agricultural land had a surface soil (0 to 10 cm) pH_{Ca} of less than 5.0. It was also estimated that a further 5.7 million hectares was at risk of developing acidic soil problems because they had a topsoil pH of 5.1 to 5.5.

A soil pH_{Ca} between 5.5 and 8.0 provides the best conditions for most agricultural plants. If the pH_{Ca} drops below 5.0, plants that are highly sensitive to acidity, such as lucerne and barley, are adversely affected. Plants that are more tolerant of acidity continue to grow normally until the pH_{Ca} falls below 4.5. Below pH_{Ca} 4.4 most plants, except the very highly acid tolerant plants like oats, narrow leaf lupins and the native pasture grass *Microlaena spp*, show a significant reduction in production.

If only the top 10 cm of the soil profile is acidic it can be readily corrected by applying and incorporating finely ground limestone. However, if acidification of the soil continues and the surface pH_{Ca} drops below 5.0 the acidity will leach into the subsurface soil (Figure 2a). The further the acidity has moved down the profile the greater the effect on plant growth and the more difficult it is to correct. This is called subsurface soil acidity and is a long term degradation of the soil. Not all areas of NSW with subsurface soil acidity have been identified, but it can be assumed that most soils with pH_{Ca} values below 4.8 in the surface soil and an

Figure 1. Soils with a low pH_{ca} and soils at risk of developing a low pH_{ca}.



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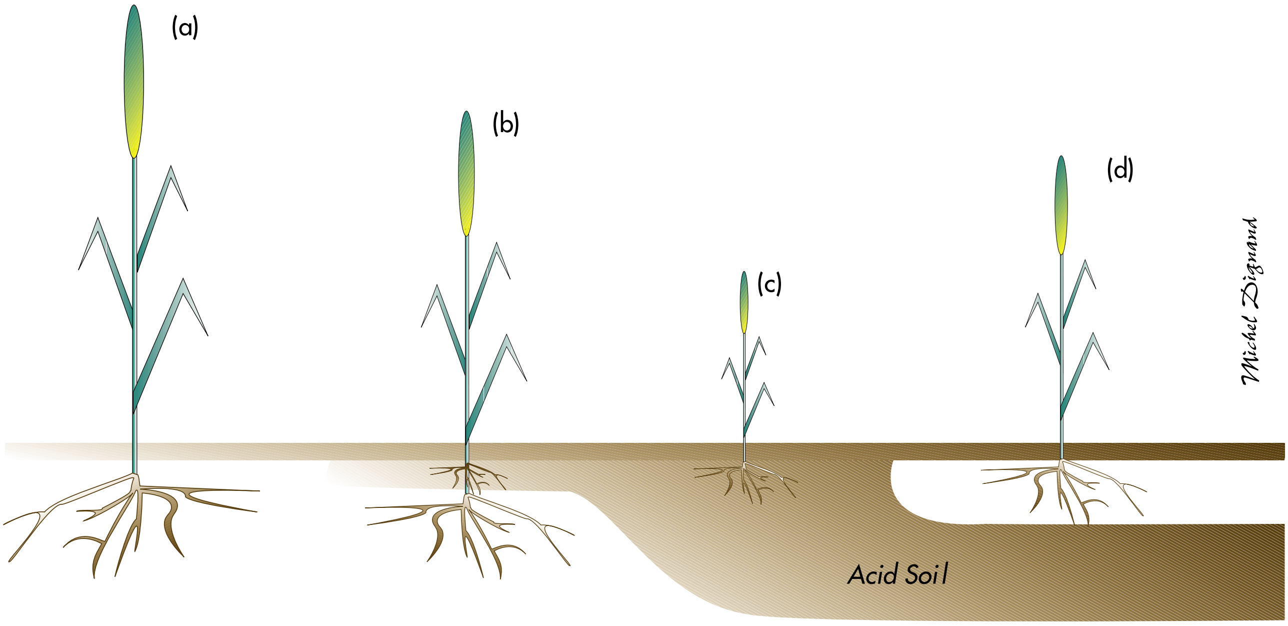
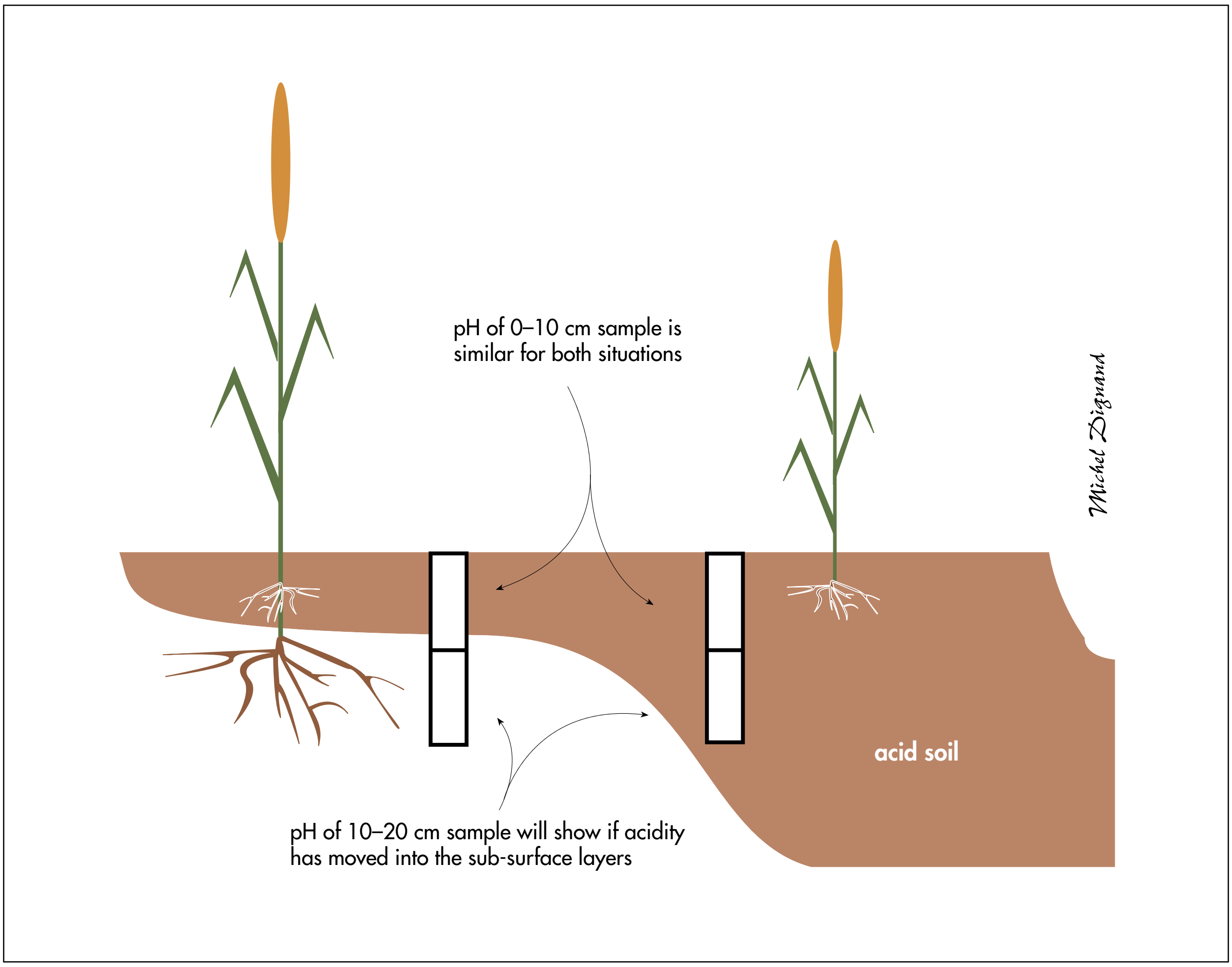
[1] pH in 1:5 soil:0.01 M CaCl_2 – see 'Measuring soil pH' page 6.

Figure 2a. The development of subsoil acidity and the implications for acid sensitive plants.



a) No acidic soil problems.
b) Acidification starts at the surface restricting surface root development.
c) Acidity is leached to depth when the pH_{Ca} of the surface soils drops below 5.0 and all root growth is restricted.
d) Subsurface soil acidity is permanent as surface applied lime only corrects acidity in the surface soil.

Figure 2b: Sampling of the 10–20 cm (subsurface) soil layer, as well as the surface soil, indicates whether acidity is a problem in subsurface layers.



average annual rainfall of at least 500 mm would have developed acidic subsurface soils.

The pH_{Ca} of a soil rarely falls below 3.8. If further acid is added to a soil, it causes a breakdown of the clay minerals. This is a permanent change to the soil and cannot be reversed. Soils that are very acidic, with pH less than 3, are usually associated with acid sulphate conditions and these soils are not discussed in this Agfact.

THE IMPACTS OF SOIL ACIDITY

Farmers see the direct impacts of soil acidity as lost productivity and reduced income through:

- reduced yields from acid sensitive crops and pastures
- poor establishment of perennial pastures
- failure of perennial pastures to persist.

Acidic soils also impact on the community.

- There is permanent degradation of the soil when the acidity leaches to a depth where it cannot be practically or economically corrected (Figure 2b.). This is a slow process and will most likely affect future generations more than it affects the present land managers.
- Recharge of aquifers is due to less water use by plants affected by soil acidity. This can lead to dryland salinity and damage to infrastructure such as the break up of roads.
- There is an increase in soil erosion and addition of silt and organic matter to waterways as annual vegetation predominates on acidic soils, leaving the soils exposed to erosion for a significant part of the year.

The details of the impact of soil acidity on specific crops and pastures are explained in the section 'How soil acidity reduces crop and pasture production'**.**

RECOGNISING SOIL ACIDITY

The signs of soil acidity are more subtle than the clearly visible symptoms of salinity and soil erosion.

Cereal growers may predict that their soil is acidic when acid sensitive crops fail to establish, or crop production is lower than expected, particularly in dry years. In pasture paddocks poor establishment or lack of persistence of acid sensitive pastures such as lucerne, and to a lesser degree phalaris, is an indication that the soil may be acidic.

More definitive indications of acidic soil are:

- Stunted or shallow root growth in crops and pastures (see photos 1,2, 3 and 4)
- poor nodulation in legumes or ineffective nodules (see photos 5 and 6)

Photo 1: Subterranean clover root stunting due to increasing aluminium.

Photo2: Acid tolerant triticale on right grew much better than acid sensitive barley on left.

- manganese toxicity symptoms in susceptible plants (see photos 6 and 7).

Soil tests

A soil test is the most reliable way to assess if soils are acidic. A comprehensive chemical analysis of the surface soil (0–10 cm depth) gives information that will assist farmers in determining if a crop or pasture will be affected by acidity. In order to assess whether acid sensitive crops will be affected by subsurface acidity, it is recommended that subsurface soil (10 cm to 20 or 30 cm) be tested for pH.

Photo 3: Berseem clover grown in a high aluminium (pH_{Ca} 4.0) soil. The small purple leaves are characteristic of aluminium toxicity in clover.

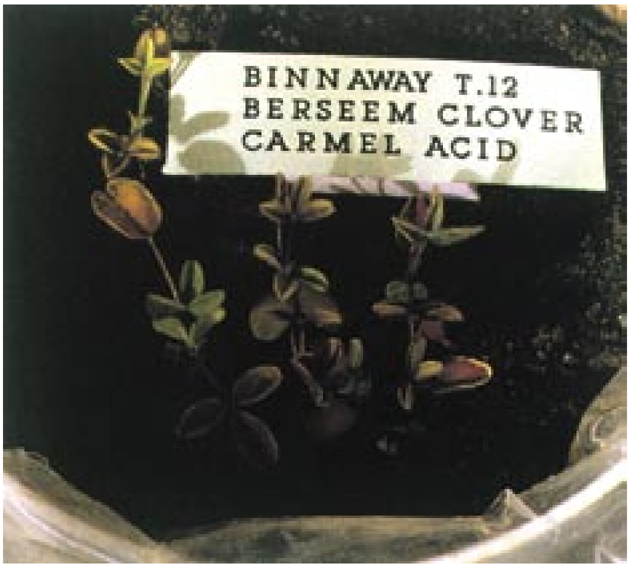


Photo 4: The effect of aluminium toxicity on the roots of wheat plants. From left to right the plants were grown in solutions containing 0, 5 and 10 ppm aluminium.

For soil tests to be meaningful, paddocks need to be divided into management units for sampling. For example, dividing the paddock on the basis of slope and aspect. To be confident that the soil sample which goes to the laboratory represents the variability of the paddock, it is necessary to collect and thoroughly mix 30 cores (or greater than 0.5 kg of soil) from each management unit.

Common soil analysis includes the following tests:

- soil pH_{Ca} or soil pH_w. (See **Measuring soil pH** below for an explanation of these terms.)
- exchangeable cations and their percentage of the ECEC (see the Glossary for explanation of terms)
- available phosphorus
- electrical conductivity (EC)
- soil texture.

Measuring soil pH

Acidity and alkalinity in any solution is measured as pH. Soil pH is an estimate of the acidity/alkalinity of the soil solution, which is the water that is held in the soil (Figure 3). Most soil pH measurements in Australia are made by shaking soil samples for an hour in either a 1:5 soil to water suspension (pH_w) or a 1:5 soil to 0.01M calcium chloride suspension (pH_{Ca}) and using an electrode to measure the pH of the resultant mixture.

The pH measured in calcium chloride is on average 0.5 to 0.8 less than pH measured in water, although the difference can vary from nil to 2.0 for different soils. In this Agfact, pH is nominated as pH_{Ca}.

The timing for collection of the soil sample and the sampling depth are important as the acidity of soil varies throughout the year, and down the profile. The pH in summer is in most circumstances higher than that in winter by up to 0.5 of a unit. This is important when making recommendations for winter crops based on analysis of samples taken over summer.

The pH varies down the soil profile, the surface soil usually being more acidic than the subsurface soil layers. In this Agfact, recommendations are made on the basis that the samples for analysis are taken to a depth of 10 cm, in late summer or early autumn.

If the pH_{Ca} of the 0–10 cm layer is less than 4.8 then the subsurface soil may be acidic. In higher rainfall areas, subsurface soil layers are more likely to be acidic. The failure of lucerne to persist over summer after lime has been applied is a potential indicator of an acid subsurface soil (Figure 2b). The only reliable way to determine if a paddock has an acidic subsurface soil is to sample and analyse the 10–20 cm, and possibly 20–30 cm layers.

CAUSES OF ACIDIFICATION OF THE SOIL

Acidification of the soil is a slow natural process and part of normal weathering. Many farming activities cause an increase in the rate of acidification of the soil. Changes in soil pH_{Ca} under agricultural use are measured in tens or hundreds of years rather than thousands of years as in the natural environment.

There are four ways that agriculture contributes to the accelerated acidification of the soil and these are shown in Figure 4.

They are:

- use of fertilisers containing ammonium or urea
- leaching of nitrate nitrogen sourced from legume fixation or from ammonium fertilisers
- removal of produce
- build-up of soil organic matter.

In some older texts the removal of 'base' cations, that is calcium, magnesium, potassium and sodium, is given as a cause of soil acidity. This is misleading, and in a similar vein acidity cannot be corrected by applying calcium.

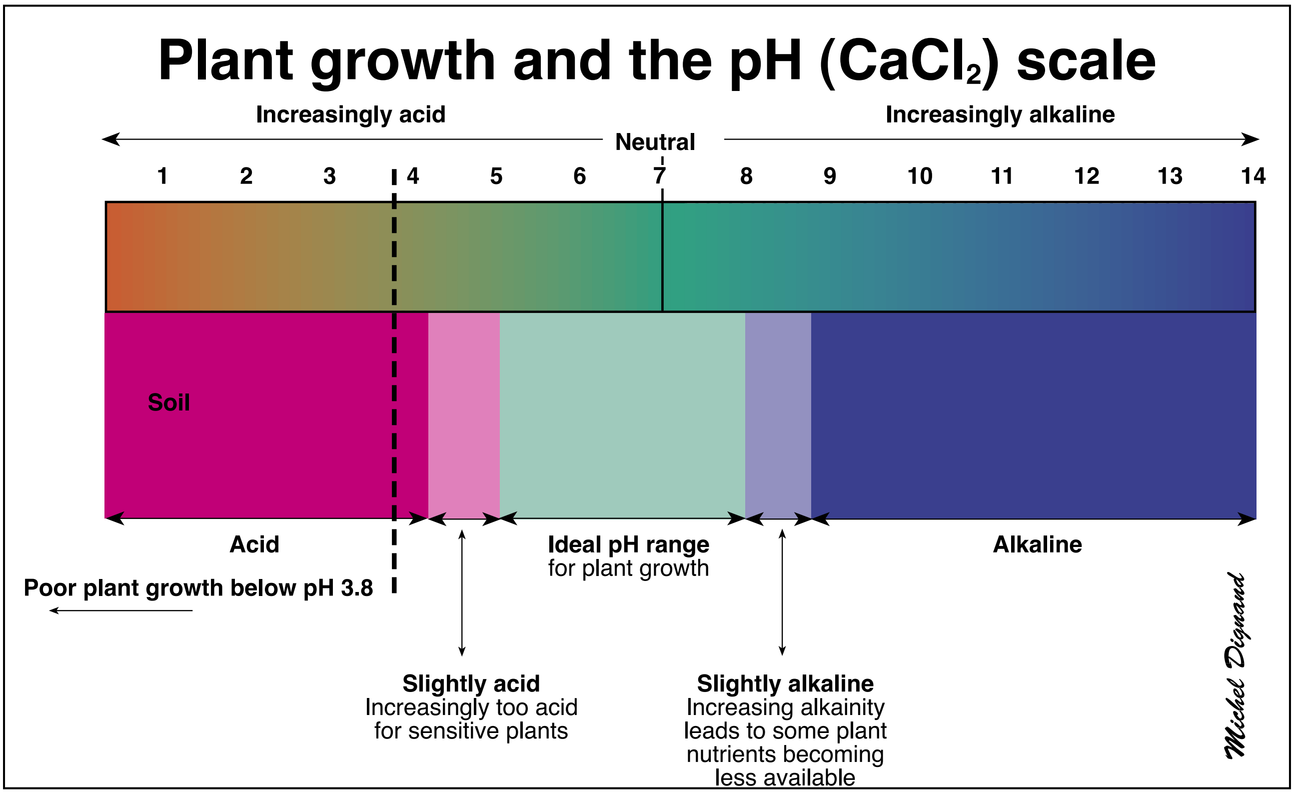
Leaching of nitrate nitrogen

Leaching of the nitrate form of nitrogen is a major contributor to agriculturally induced soil acidification. Nitrate nitrogen is produced in the soil by the breakdown of organic matter, or of ammonium forms of nitrogen.

The chemical processes that produce nitrate nitrogen from fertiliser and organic matter leave the soil slightly more acidic. This acidity is neutralised by plants discharging an alkaline substance as they take up nitrate nitrogen and to a smaller extent by conversion of nitrate nitrogen to nitrogen gas.

While the plants continue to take up all the nitrate nitrogen, the acid/alkali balance of the soil surrounding the roots remains in balance. Nitrate nitrogen is very soluble and easily

Figure 3. Plant growth in relation to pH, and examples of some of commonly used terms to describe effect of acidity/alkalinity on plant growth.



leached. Leaching breaks the balance of the acid/alkali processes and results in increased soil acidity. Deep rooted perennial plants reduce the risk of leaching which is most prevalent in autumn/early winter. Perennial plants are more suited to control leaching as they are able to grow quickly after the ‘autumn break’ rains and capture soil water before leaching can occur. Where farming systems are based only on annual plants, leaching can occur before new root development has occurred.

Use of nitrogenous fertilisers and legume pastures

The amount of acidification that results from using nitrogenous fertilisers depends on the fertiliser type (Table 1). Fertilisers that contain nitrogen as ammonium, for example ammonium

Figure 4. Agricultural practices that increase the rate of soil acidification.

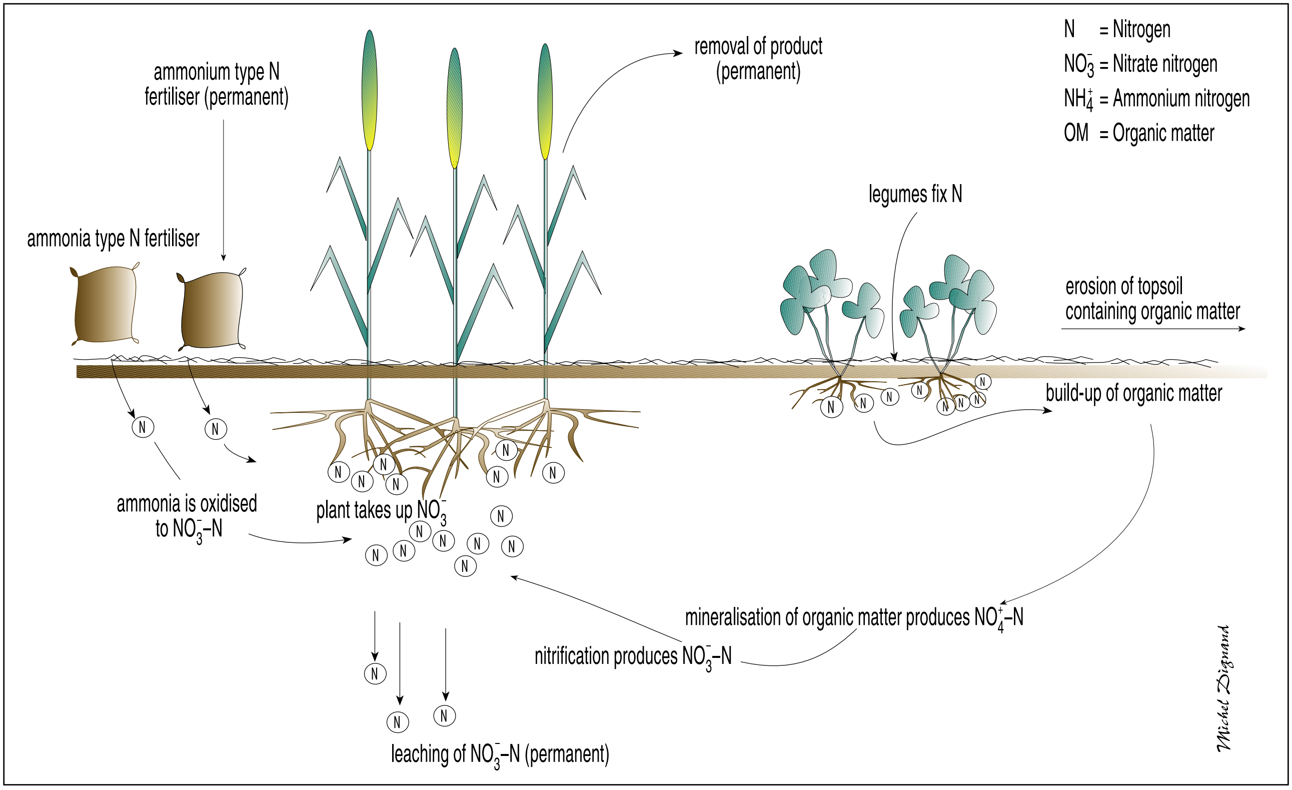


Table 1. Acidifying effect of nitrogenous fertilisers and legume-fixed nitrogen in terms of lime required to neutralise the acid added.

Source of nitrogen	Lime required to balance acidification (kg lime/kg N)		
	0% nitrate leached	50% nitrate leached	100% nitrate leached
High acidification Sulphate of ammonium, Mono-ammonium phosphate (MAP)	3.7	5.4	7.1
Medium acidification Di-ammonium phosphate (DAP)	1.8	3.6	5.3
Low acidification Urea Ammonium nitrate Aqua ammonia Anhydrous ammonia Legume fixed N	0	1.8	3.6
Alkalisation Sodium and calcium nitrate	−3.6[1]	−1.8	0

[1] Equivalent to applying 3.6 kg lime/kg N.

sulphate, acidify the soil within weeks after application. Calcium nitrate and sodium nitrate have a neutralising effect on soil acidity, unless all the nitrate is leached (Table 1) but they are expensive and use is restricted to horticulture.

Using superphosphate fertiliser on crops and pastures does not directly acidify the soil. However, its use stimulates growth of clover and other legumes, resulting in a build-up in organic matter which in turn increases soil acidity. Also there is an increase in nitrate nitrogen in the soil that comes with the higher levels of organic matter. This increases the likelihood of soil acidification from leaching of nitrate nitrogen.

Applying pure sulphur or 'flowers of sulphur' will acidify the soil. An application of 3 kg of limestone for each kg of sulphur is required to neutralise this effect.

Removal of produce

Grain, pasture and animal products are slightly alkaline and continued removal will lower the soil pH over time. This contribution to acidity is part of the 'carbon cycle' (see the Glossary). If very little produce is removed, such as in wool production, then the system remains almost balanced. Where a large quantity of produce is removed as in the case of hay making (particularly clover or lucerne hay), the soil is left significantly more acidic. For details on the quantity of lime needed to neutralise acidity relating to common agriculture products see Table 2.

Removal of produce by burning, for example burning of stubble, does not change the acid/alkali balance of the soil, but gives a redistribution, leaving alkali at the soil surface as ash. If the ash is then washed away, as might occur after a fire, this would leave the soil more acidic.

Build-up of soil organic matter

Over the last 50 years the regular use of fertiliser and improved pastures, particularly subterranean clover, has generally led to increased organic matter in the soil. While increasing organic matter has many benefits, including improvement of soil structure, it also increases soil acidity. The build up of organic matter will not continue indefinitely, and there is no further acidification due to this cause once the organic matter stabilises at a new level.

The acidification caused by a build up in organic matter is not permanent and can be reversed if the organic matter breaks down. However, there will be a permanent change in the acid status of the soil if the topsoil containing the organic matter is eroded or removed.

The relative importance of these causes of soil acidification for two farming systems is given in Table 3.

A simple demonstration of the extent to which agricultural land use has acidified a paddock is to compare the soil test of the paddock with a similar test of a sample collected from an area close to the paddock that has not been cultivated or fertilised, such as an adjacent roadside.

Table 2. The amount of lime needed to neutralise the acidification caused by removal of produce.

Produce removed	Lime requirement kg/t of produce
Milk	4
Wheat	9
Wool*	14
Meat*	17
Lupins	20
Grass hay	25
Clover hay	40
Maize silage	40
Lucerne hay	70

* Further acidification occurs with set stocking of sheep due to the uneven deposition of animal excreta in stock camps.

Table 3. Estimates of the relative importance of factors causing agriculturally induced soil acidity for two farming systems.

Cause of acidification	Annual pasture Southern Tablelands NSW(%)	Cropping/pasture rotation, Wagga Wagga (%)
Leaching of nitrate nitrogen	50–70	50–70
Build-up of soil organic matter	10–30	Nil or reverse
Removal of product	10–30	20–30
Use of nitrogenous fertilisers	n/a	5–10

HOW SOIL ACIDITY REDUCES CROP AND PASTURE PRODUCTION

Nutrient solubility, and thus availability to plants, varies with soil pH. Some nutrients may reach toxic levels, while others become unavailable leading to deficiencies. The increased availability of aluminium in the soil solution associated with declining pH is an example of this, aluminium toxicity being a major problem for crop and pasture production in acid soils.

Other production losses may occur where acidity reduces the activity of beneficial soil micro-organisms. It is recognised that the nitrogen fixation by *Rhizobia spp.* on legume roots is retarded in acid soils, resulting in lower nitrogen availability and reduced production.

In general the changes in the availability of plant nutrients associated with increasing soil acidity are:

- Increased available aluminium (Al^{3+}) causing stunted root development in crops and pastures (see photos 1, 2, 3 and 4). Stunted roots result in reduced capability to access soil moisture, and reduced nutrient uptake.
- Increased available manganese (Mn^{2+}) causing reduced growth in some plants in some soils (see photos 3, 4 and 5).
- Reduced solubility and availability of molybdenum, phosphorus, magnesium and calcium.

The actual amount of aluminium and manganese in solution in a soil at a given pH varies between different soil types. Weakly weathered soils that are acidic tend to release toxic amounts of soluble manganese, but lesser amounts of aluminium. Alternatively, highly weathered soils (other than a group of soils high in iron and aluminium oxides) tend to release large amounts of aluminium and lesser amounts of manganese.

Different soils release different amounts of aluminium and manganese at the same pH_{Ca}. As the tolerance to aluminium and manganese varies between plant species, it is not possible to recommend a single pH at which liming should begin for all situations.

The effect of aluminium (Al) toxicity

Soluble aluminium in the soil solution causes most of the problems associated with acidic soils. The principal effects on plant growth from soluble aluminium in the soil solution are:

- **Reduced root mass and function**. The principal effect of aluminium toxicity is to reduce the mass and function of roots. Generally this is seen in the field as stunted, club shaped roots. This reduces their ability to extract moisture from deep in the soil. (See photos 1, 2, 3 and 4.)
- **Tying up phosphorus**. Soluble aluminium immobilises phosphorus in the soil and the plant, causing symptoms of phosphorus deficiency, that is, small and dark-green or occasionally purple leaves. The symptoms become more pronounced as the aluminium level increases.

Note that applying lime to strongly acidic soils slightly increases plant access to soil phosphorus that is normally of low availability (such as residues of previously applied fertiliser). This effect is usually small, and normal phosphorus applications are still required when lime is used.

- **Reduced availability of calcium and magnesium**. Very high levels of aluminium in the soil also reduce the uptake and utilisation of calcium and magnesium.

Aluminium toxicity does not usually occur in soils where the pH_{Ca} is above 5.2. Applying sufficient lime to lift the pH_{Ca} above 5.5 will remove aluminium from the soil solution.

Alternatively the impact of aluminium can be reduced by growing plants that can tolerate aluminium. Different plants show different levels of tolerance to soluble aluminium levels in soil. See Table 4.

Soil testing for aluminium

Two methods are commonly used to measure available aluminium in the soil. The first method measures the aluminium in the 0.01M $CaCl_2$

Photo 5: Yellow leaf margins of clover indicate manganese toxicity in the soil.

extract used to determine pH_{Ca} and is called the calcium chloride extractable aluminium, Al_{Ca}. This is the best estimate of the aluminium that will be encountered by the plant root. It gives the best prediction of the effect of aluminium on plant growth.

The alternative method measures the exchangeable aluminium as part of the determination of the effective cation exchange capacity (ECEC – see the explanation in the Glossary). The proportion of aluminium in the ECEC expressed as a percentage (Al_{ex}), reflects the aluminium in the soil solution. This measurement is determined routinely by commercial laboratories. When interpreting these results the electrical conductivity (EC) of the soil is needed to accurately predict the effect of the aluminium on plant growth. Table 5 shows critical concentrations of calcium chloride extractable aluminium (Al_{Ca}) and the exchangeable aluminium percentage (Al_{ex}) for different electrical conductivities for the major groups of plant tolerance to aluminium. A critical concentration is one that will reduce plant growth by 10%.

Note when the organic matter is over 5% it may adsorb soluble aluminium resulting in sensitive plants being able to grow in soils with a low pHCa. These plants will often have shallow roots as the subsurface soil contains little organic matter and is therefore high in soluble aluminium. Both soil tests, calcium chloride extractable and the exchangeable aluminium, will indicate a reduction in the available aluminium caused by organic matter taking the aluminium out of solution.

The effect of manganese (Mn) toxicity

Toxicity from excessive amounts of available manganese can affect the growth of crops, pasture and horticultural crops in soils where pH_{Ca} is less than 5.5, but only in some soils and then only at certain times of the year. Plants require manganese in small amounts for photosynthesis and for several enzymes including those controlling the plant hormones. Toxic amounts of manganese disrupt photosynthesis and the function of plant hormones.

Toxic levels of manganese do not affect the productivity of crops and pastures to the same extent as aluminium toxicity. Manganese toxicity effects are sometimes complicated by related problems. The anaerobic conditions associated with waterlogged soils induce manganese toxicity but, other problems such as loss of gaseous nitrogen may result in more yield losses than the toxic manganese.

While both toxicities and deficiencies of manganese can occur in NSW, the main problem

Table 4. Aluminium sensitivity (tolerance) of some crop and pasture plants.

Highly sensitive	Durum wheat, most barley cultivars, faba beans, lentils, chickpeas, lucerne, medics, Strawberry, Berseem and Persian clovers, Buffel grass, tall wheatgrass
Sensitive	Cunningham & Janz wheat, Canola, Yambla barley, albus lupins, red grass (Wagga), wallaby grass (*D. linkii*), phalaris, red clover, Balansa clover, Caucasian and Kenya white clovers.
Tolerant	Whistler, Sunstate & Diamondbird wheats, annual & perennial rye-grass, tall fescue, Haifa white and subterranean clovers, chicory.
Highly tolerant	Narrow leaf lupins, oats, triticale, cereal rye, cocksfoot, kikuyu, paspalum, yellow & slender serradella, Maku lotus, common couch, Consol love grass

These are only examples. For the current information on the tolerance of current varieties of winter crops to soil acidity see the *Winter crop variety sowing guide* published annually by NSW Department of Primary Industries.

Table 5. Critical concentrations of calcium chloride extractable aluminium

Aluminium tolerance of plants (Table 4)	Critical levels Al_{Ca} mg/L	Equivalent % Al_{ex} for soils at different electrical conductivities (EC 1:5 dS/m)		
		Low EC < 0.07	Med. EC 0.07–0.23	high EC > 0.23
Highly sensitive	0.1–0.4	9–16	2–8	0.5–2
Sensitive	0.5–0.8	17–20	9–12	3–6
Tolerant	0.9–1.6	21–32	13–21	7–10
Highly tolerant	1.7–2.7	33–43	22–30	11–16

is toxicity. However, excessive applications of lime may result in manganese deficiency in some light textured soils.

The visual symptoms of manganese toxicity in some common agricultural plants are:

- **Canola.** The effect of manganese toxicity is reduced vigour with yellowing of the leaf margins (see photo 7). Higher levels of manganese result in yellowing of the whole leaf, necrosis of the leaf margins and greatly reduced vigour or death. In most seasons canola grows despite the toxic effects of manganese as the solubility of the manganese drops in late autumn.
- **Lucerne, medics, serradella and sub clover.** The effect of excess manganese is reduced seedling vigour and red or yellow leaf margins. Normal growth rates return with a decrease in available manganese as the season progresses. If warm to hot conditions return after the first germination the level of available manganese increases, renewing the effect and possibly causing death of the seedlings. The seedlings of legume pasture species germinating in the autumn can be affected by high levels of available manganese. Lucerne and most medics are highly sensitive, while sub clover and serradella seedlings are only affected by higher levels of manganese.
- **Grasses.** Lack of seedling vigour, yellowing at the tips and margins, and some flecking of the older leaves are indicators of manganese toxicity (see photo 6). However, other nutritional problems can have similar effects in grasses and tissue analysis is required to confirm manganese toxicity.

Plant analysis

Because of the complexity of identifying toxicity using visual symptoms, analysis of plant tissue can help to determine if there is a toxic manganese problem.

Some plants are affected by only a small amount of manganese in the tissue, while others are tolerant of high levels. The concentration of

Photo 6: The effect of manganese toxicity on Teal wheat. From left to right plants were grown in solutions ranging from 0, 90 to 180 ppm manganese.

Photo 7: Canola leaves that are cup shaped with yellow margins indicating manganese toxicity.

manganese in plants at which a small decline in growth will occur can vary from 200 to over 1000 mg/kg of plant dry matter, depending on the tolerance of the plant. Critical manganese levels sufficient to cause a 10% decline in growth for a number of species are given in Table 6. These levels are determined on the youngest fully developed leaf.

Some plants are more sensitive to aluminium than to manganese and vice versa. For example, white clover is tolerant of aluminium but sensitive to manganese.

Seasonal changes in availability of manganese

The availability of manganese can vary up to four-fold through the year as shown in Figure 5. Manganese is most available in summer when hot and dry conditions stimulate the chemical changes from an unavailable form (oxidised) to an available form (reduced). This effect is less in a wet summer.

Waterlogged conditions in spring can produce high levels of available manganese. However, low levels of oxygen and loss of nitrogen associated with waterlogging are likely to affect the plants more than the high manganese levels.

Rain in autumn creates a soil environment that favours microflora which convert the manganese back to an unavailable (oxidised) form. It follows that the availability of manganese is at its lowest in winter, although potentially toxic levels may remain if the conditions are too cold in autumn (soil temperatures less than 10°C) for the microflora to change the available manganese to the unavailable form.

Soil testing for available manganese

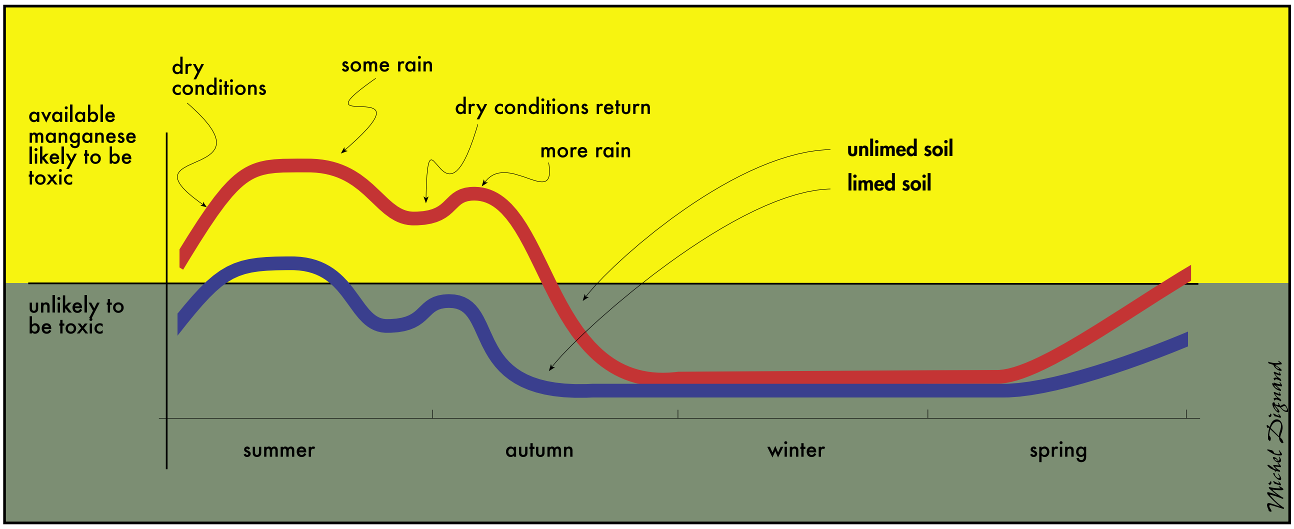
Because the levels of available manganese can vary up to four-fold through the year in response to temperature and rainfall, a soil test which measures available manganese at one time in the year cannot be relied on to determine if manganese toxicity is likely to be a problem at another time. For example, it is not possible to predict the level of available manganese in April, when sowing canola or lucerne, from a soil sample taken in February.

Table 6. Critical levels of manganese for various plants.

Manganese tolerance category	Plant	Critical leaf manganese level (mg/kg)
Highly sensitive	Lucerne, pigeon pea, barrel and burr medics	200–400
Sensitive	White clover, strawberry clover, chickpea, canola	400–700
Tolerant	Sub clover, cotton, cowpea, soybean, wheat, barley, triticale, oats	700–1000
Highly tolerant	Rice, sugar cane, tobacco, sunflower, most pasture grasses, oats, triticale, Tiga, Currency, cereal rye	> 1000

See NSW DPI *Winter crop variety sowing guide* for more information.

Figure 5. Variation of manganese availability with season.



This problem can be overcome by using soil tests that determine the potentially available manganese (the maximum that could become available under the most harmful conditions) rather than that which is available at the time of testing and then to estimate the available manganese based on the time of the year and soil conditions at sowing.

To assist in the interpretation of soil test results, Table 7 lists three tests that are commercially available and a research test that gives potentially available manganese, the form of manganese that is extracted by each test, and the range of results that might be expected. Note that the values obtained from different tests *can not* be compared in absolute amounts.

Managing toxic levels of soil manganese

Applying lime sufficient to lift the pH_{Ca} to above 5.5 will decrease available manganese. Alternatively, the effects of manganese toxicity on autumn sown crops and pastures which are sensitive to manganese can be decreased by sowing on the second autumn rain.

The effects of molybdenum (Mo) deficiency

Many Australian soils are naturally low in molybdenum and deficiencies are more likely to occur in soils with pH_{Ca} below 5.5.

All plants need molybdenum in trace amounts to facilitate the use of nitrate nitrogen. Molybdenum deficiency causes an accumulation of unused nitrate nitrogen, resulting in irregular twisting of the leaves. The whole plant may be pale green and the older leaves can also show chlorotic striping and burnt leaf margins.

Legumes have higher molybdenum requirements than grasses and cereals as molybdenum plays a part in the nitrogen fixing process. Where molybdenum is deficient, nitrogen fixing nodules occur more frequently than usual and when opened the normal pink colour is replaced with a pale green (indicating that they are not functional). The symptoms of a molybdenum deficiency in a legume are those of a nitrogen deficiency, that is, pale green to yellow leaves.

Correcting a molybdenum deficiency

Because molybdenum is required in such small amounts a soil test is not a reliable method for assessing if there is a deficiency. The only recommendation is that where the pH_{Ca} of a soil is below 5.5 a response in legumes and some cruciferous vegetables may occur to an application of 50–100 g of sodium molybdate per hectare. This response varies and local information from your district agronomist or fertiliser outlet should be sought before proceeding. An application every 3–5 years (depending on soil type) as a spray of sodium molybdate or molybdenum trioxide, or as a component of a fertiliser, is sufficient for all plants. A lime application that increases pH_{Ca} by one unit, for example from 4.5 to 5.5, increases the availability of both applied and naturally occurring molybdenum.

The effects of calcium (Ca) deficiency

Calcium is required to form new plant cells, so it is essential for the growing points of shoots and roots, for root hair and for leaf development. Low levels of soil calcium also adversely affect the nodulation of legumes. Short term deficiency can cause petiole collapse of young expanding leaves.

Most soils in NSW have an adequate supply of available calcium for field crops, pastures and horticultural crops. Vigorously growing plants in marginal calcium soils will show symptoms on the parts of the plant that are furthest from the

Table 7: Tests for soil manganese that are commercially available.

Extraction method	Form of Mn extracted	Likely range of values (mg/kg soil)
1:10 soil:solution DTPA Triethanolamine $CaCl_2$	soluble + exchangeable	4–50
1:5 soil:solution 0.05 M EDTA	soluble + exchangeable + portion of potentially reducible	50–600
1:5 soil:solution 0.01 M $CaCl_2$	soluble + exchangeable	0–175
1:10 hydroquinone in 1 M ammonium acetate	potentially available	0–1200

Photo 9: Rhizobia nodules from a medic. Pink nodules on the left are active, white/green nodules on the right are non-functioning.

Photo 10: Tomato blossom end rot.

main flow of water. Blossom end rot in tomatoes (Photo 10) and watermelons and poor seed set in peanuts and subterranean clover are examples of the effect of moderate calcium deficiency. More severe calcium deficiency causes death of growing points, for example November leaf in bananas.

Very severe calcium deficiency is very rare and will only occur in acidic soils that are sandy and low in organic matter, or where there has been excessive use of highly acidifying fertilisers. Under these circumstances the percentage of exchangeable calcium of the ECEC can drop to low levels (< 40%), leaving the exchangeable aluminium as the dominant exchangeable cation (see the Glossary for an explanation of these terms). The symptoms may appear as stubby, unbranched and discoloured roots or as dead growing points in the shoots. The root symptoms are difficult to distinguish from symptoms of aluminium toxicity.

The effects of magnesium (Mg) deficiency

Magnesium deficiency has been recorded in seedling crops and pastures in light soils

Photo 8: Lucerne plants showing leaf yellowing characteristic of molybdenum deficiency. Similar symptoms occur where nitrogen is deficient.

in southern NSW where there is less than 0.2 meq/100 g exchangeable magnesium in the 0–10 cm soil layer, but such reports are rare. Usually these crops or pastures recover by spring, as nearly all soils in NSW have an ample supply of magnesium in the subsoil that plants access as their roots extend down the profile.

The signs of magnesium deficiency in cereals are yellowing of the oldest leaves and this can be confused with nitrogen deficiency. In clovers the symptoms can include reddening of the oldest leaves.

Magnesium and soil structure

There have been some reports that high levels of magnesium (exchangeable Mg > 50% of ECEC) may cause loss of structure in soil. Research has shown that magnesium itself has no effect on spontaneous dispersion of undisturbed soil. It can, however, affect dispersion of a soil that has been cultivated.

Where the exchangeable magnesium is greater than 30% of the ECEC it may enhance the effect of sodium in causing dispersion of a soil, provided that the Ca:Mg ratio is less than 1 and:

- the ESP > 4% and/or
- the sum of ESP plus (Ex.Mg% divided by 10) is greater than 6.
  (See glossary for explanation of terms.)

In practice this means that when the ESP is more than 6%, the contribution of sodium (Na) is much more important than that of magnesium. ESP is the principal measurement used to predict soil dispersion. Note that the critical values of Mg and Na for dispersion given above are for a soil with a low electrical conductivity (EC < 0.2 dS/m in 1:5 soil:water). As the electrical conductivity increases, so will the critical value of (ESP plus Mg/10) need to increase to cause dispersion.

Magnesium and grass tetany in cattle

The onset of grass tetany in cattle is sometimes attributed to a low soil magnesium but a number of factors might influence the onset of this condition. Check with a veterinarian or livestock officer before applying dolomite or magnesite to correct a grass tetany problem. There may be more effective and less expensive ways to reduce the occurrence of grass tetany in cattle.

Using the Ca:Mg ratio to predict plant growth

Since 1901 there have been claims that the ratio of exchangeable calcium to exchangeable magnesium needs to be of the order of 4 to 6 to achieve a 'healthy' soil and therefore optimum agricultural production. This claim has not been proven. Furthermore, there have been several scientific reports that show that the Ca: Mg ratio can vary significantly with no effect on agricultural production.

Effect of soil acidity on the micro-organisms that affect plant growth

Sometimes the effect of acidic soils on the growth and production of crops and pastures is not direct but rather through the effect on soil micro-organisms that in turn affect plant growth.

Photo 11: Rhizobia on lucerne roots.

Reduced fixation of nitrogen

Acidity reduces the survival of Rhizobia and the effective infection of legume roots. The sensitivity to acidity varies greatly between species. When a Rhizobia sp is affected by soil acidity it shows as poor nodulation and results in reduced nitrogen fixation. Often Rhizobium bacteria are more sensitive to soil acidity than the host plant, for example lucerne and medics.

Lime pelleting of inoculated legume seed is used to protect the inoculum against drying out and contact with fertiliser. Sowing into bands of lime-super also creates an environment suitable for survival of the inoculum in an acidic soil.

For further information on the effect of soil acidity on legume nodulation and how to manage it, see Agfact P2.2.7, *Inoculating and pelleting pasture legume seeds.*

The effect of pH_{Ca} on the activity of Take-all root disease in cereals

The fungus that causes the root disease Take-all in cereals, *Gaeumannomyces graminis* var.

tritici, is most active in soils with a pH_{Ca} greater than 4.8, and has a low level of activity in soils with a pH less than 4.6. Liming greatly increases the activity of Take-all.

Wheat and triticale should not be grown after liming a paddock unless the population of the fungus has been greatly reduced with a break crop or early fallow. Take-all can build up rapidly in wet seasons on roots of wheat, barley, triticale and many grasses and pose a threat to wheat grown in the paddock the next year. A break crop of a broadleaf crop (canola, lupins, peas, etc.) or winter cleaning of grasses from clover or lucerne pastures reduces the threat from take-all and should be done routinely after liming.

REDUCING THE IMPACT OF SOIL ACIDITY ON AGRICULTURE

Growing acid tolerant crops and pastures

If a paddock is already acidic, particularly where both the surface and subsurface soils are acidic, the economic and downstream impacts and the rate of acidification can be reduced by growing acid tolerant crops and pastures.

Acid tolerant species can help farmers to reduce the impact of soil acidity by:

- maintaining cash flow if limestone cannot be applied when required
- maintaining or increasing production on soils with acidic subsurface layers that are too deep to be limed economically, or are on non-arable land
- slowing the rate of acidification with more efficient use of nitrate nitrogen and soil moisture; particularly by replacing annual winter grasses with vigorous, perennial grasses that have some summer growth
- allowing crop and pasture rotation sequences to match the typical decline of soil pH_{Ca} during a 10–15 year liming cycle
- increasing water use and ground cover and thus reducing the downstream impacts.

Acid tolerant plants may slow the acidification of the soil but will not prevent it. Eventually the soil will become so acidic that only the most tolerant species can grow, and then with reduced production.

Where the soil is very acidic and sowing acid tolerant species is not practical then retiring land from agriculture may well be the best option for the farm and the environment.

Refer to the list of aluminium tolerant crops and pastures in Table 4 when selecting crops and pastures for acidic soils. Tolerance of plants to aluminium closely reflects acid soil tolerance in all soils except the weakly weathered soils.

Protecting soils at risk of becoming acidic

Where soils are at risk of becoming acidic the future impact of soil acidity can be reduced, but not eliminated, by slowing the rate of acidification. This can be achieved by:

- minimising leaching of nitrate nitrogen
- using less acidifying fertilisers
- reducing the effect of removal of product
- preventing erosion of the surface soil.

Reducing the leaching of nitrate nitrogen

Nitrate nitrogen (NO_3-N) is easily leached as it is highly soluble. When NO_3-N is leached away it leaves that part of the soil more acidic. If the NO_3-N is taken up further down the profile there can be an increase in pH_{Ca} at the point of uptake. However when the NO_3-N is leached below the root zone it leaves the soil profile more acidic (Figure 4).

Table 8 lists the factors that affect NO_3-N leaching in order of importance. It qualifies the effect of each factor and indicates how the effect can be influenced. The absolute effect of each factor will increase with higher rainfall.

Using less acidifying fertilisers

Acidification of the soil can be reduced by avoiding the use of highly acidifying fertilisers such as sulphate of ammonium and mono-ammonium phosphate (MAP) (see table 1). Nitrogen fertiliser (including urea) that is pre-sown should be drilled into narrow bands to slow nitrification and subsequent leaching. Surface application of nitrogenous fertiliser for crops before sowing, even if harrowed, can result in acidification due to nitrate leaching. Nitrate nitrogen will be better utilised by applying top-dressed nitrogen to actively growing rather than dormant crops, resulting in less acidification risk.

The acidification caused by applying elemental sulphur can be eliminated by using products that contain sulphur in the sulphate form such as gypsum, potassium sulphate and superphosphate. Correcting acidification caused by using elemental sulphur requires 3 kg of limestone for each 1 kg of sulphur applied.

Minimising product removal effects

Grain, pasture and animal products are slightly alkaline and their removal from a paddock leaves the soil more acidic. When a large quantity of produce is removed, particularly clover or lucerne hay, the soil becomes significantly more acidic. If very little produce is removed, such as in meat or wool production, then the effect on the soil acidity is far less. The rates of limestone required to neutralise the acidification caused by removal of produce are given in Table 2.

If the produce is sold off-farm, regular liming is the only way to maintain pH_{Ca}. The effect on soil acidity of removing hay will be greatly reduced if the hay is fed back in the paddock where it was cut. On dairies, effluent from the shed should ideally be spread back on the paddocks and more than one night paddock should be used.

Preventing erosion of topsoil

A build-up of soil organic matter and/or increasing the biomass, both dead and alive, has the same effect on soil acidity as removing produce from the paddock. The increase in soil organic matter or biomass will stabilise at a new level over time and can be reversed if the biomass is reduced and the organic matter mineralised.

However, if the topsoil is removed by erosion the increase in the acidity of the soil is permanent. Similarly if the biomass is burned and the ash is washed or blown away then soil is left a little more acidic.

Higher organic matter levels often mean higher levels of available nitrate nitrogen and the potential for further acidification due to leaching.

MANAGING SOIL ACIDITY WITH LIMESTONE

Application of finely crushed limestone, or other liming material, is the only practical way to neutralise soil acidity. Limestone is most effective if sufficient is applied to raise the pH_{Ca} to 5.5 and it is well incorporated into the soil. Where acidity occurs deeper than the plough layer, the limestone will only neutralise subsurface soil acidity if the pH_{Ca} of the surface soil is maintained above 5.5.

The liming materials most commonly used are agricultural limestone and dolomite, but other materials are available. A list of the principal liming materials, together with some of their properties, is given in Table 9.

Table 8. Factors that affect NO_3-N leaching in order of importance.

Factor affecting NO_3-N leaching	Nature of effect	Reducing the effect
Poor plant growth	Inefficient water use increases leakage of water containing NO_3-N into the sub soil and into the water table.	Efficient water use by healthy well managed crops and pastures reduces leakage into the water table.
Nitrogen fixed by clovers in pastures	NO_3-N will leach with autumn rain before annual pastures establish.	Perennial pastures will utilise the NO_3-N as it comes available soon after rain.
High clover to grass ratio in pastures	High N producing pastures increase NO_3-N available to be leached.	Aim for maximum of 30% clover, minimise annual weeds and maximise perennial grass component.
Annual crops	Delay in sowing annual crops will allow the NO_3 to move down the profile on the first water front ahead of the roots.	Sow as early as possible after weed control.
N Fertiliser	Soluble forms of N are leached away before the plant can use it	Apply top dressed N fertiliser according to N budget guidelines.
Soil pH	Higher pH increases nitrification thus increasing NO_3-N available.	Maintain high productivity (and maximise NO_3-N use) with perennial pastures and efficient crop management.
Lack of adsorption onto clay	NO_3 is weakly adsorbed by clays, so leaching occurs.	Utilise the nitrogen before it is leached. e.g. early sowing of crops, perennial pastures.

Table 9. Chemical analyses[a] of pure and commercial grades of the principal liming materials.

Liming material	Neutralising value			Calcium (% Ca)			Magnesium (% Mg)		
	Pure form	Commercial grades[a]		Pure form	Commercial grades		Pure form	Commercial grades	
		Good	Poor to fair		Good	Poor		Good	Poor
Agricultural lime (calcium carbonate)	100	95–98	60–75	40	36–39	28–32	0	Usually <3%	
Hydrated (slaked) lime (calcium hydroxide)	135	110–120	<105	54	44–49	<40	0	Usually <1%	
Burnt lime (calcium oxide)	179	128–150[b]	<120	71	49–58	<45	0	Usually <1%	
Dolomite (calcium/magnesium carbonate)	109	92–102	60–75	22	21	10–15	13	12	4–7
Burnt dolomite (calcium/magnesium oxide)	214	110–160[b]	80–100	42	25–32	–	25	12–18	–
Magnesite (magnesium carbonate)	119	95–105	–	0	0.5–1.0	–	28.6	20–28	–
Burnt magnesite (magnesium oxide)	250	180–220[b]	–	0	1–2	–	60	43–55	–

[a] Analyses of commercial grades of materials based on NSW DPI records.

[b] High values can be expected only from freshly burnt products. Burnt and hydrated lime, dolomite and magnesite readily react with carbon dioxide and moisture in the atmosphere to revert to hydrated and carbonate forms, causing their neutralising values and calcium and magnesium analyses to fall with time and exposure to air.

Limestone quality

Agricultural lime in NSW comes from naturally occurring limestone that is mined and crushed at several plants throughout eastern Australia. The quality or effectiveness of different liming products varies. All liming products sold in NSW are required to be correctly labelled under the Fertilisers Act, 1985. This means the calcium and magnesium content, fineness and neutralising values must all be stated on the label or invoice. See Table 10.

Fineness

There are two benefits to fineness. The finer particles in a liming material react more quickly in the soil as they have a greater surface area to react with acids. Secondly they will be better distributed through the soil after incorporation. Most lime crushers in NSW strive to produce a lime that has a particle size where 90% passes through a 150 µm sieve. Lime where 99% is less than 75 µm is highly reactive but requires special machinery to spread. Particles larger than 500 µm react only very slowly with the soil. There is a compromise between fineness and the cost of production, so there are practical limits on fineness.

Neutralising value

The neutralising value (NV) of a liming material is its capacity to neutralise acidity. The higher the NV the more pure is the product. Pure calcium carbonate (pure limestone) is taken as the standard with an NV of 100. The neutralising value of commercial limestone is usually between 96 and 98. Other liming materials are more reactive than limestone and therefore have higher neutralising values, for example hydrated lime and burnt lime (Table 9). In NSW the Fertiliser Act requires that the neutralising values are calculated for three particle sizes (see Table 10) to inform the buyer if there are variations in the purity of the liming material in the fractions.

Calcium and magnesium contents

The proportion of calcium and magnesium in a liming material does not greatly affect the neutralising value. The chemical form (carbonate, hydroxide, oxide or silicate) will greatly affect the neutralising value as detailed in Table 9. The hydroxide, oxide and silicate forms are hazardous to health. In extensive cropping and pasture situations, a response to the magnesium in dolomite or magnesite is unlikely as there is

Table 10. The information on lime quality that must be specified on the label of lime sold in NSW.

The proportion (expressed as w/w or w/v) in which calcium and magnesium in the following forms occur in the liming material:	
calcium	magnesium
calcium carbonate	magnesium carbonate
calcium hydroxide	magnesium hydroxide
calcium oxide	magnesium oxide
calcium silicate	magnesium silicate
The particle size distribution expressed as a % of weight passing through the following sieves:	
1,000 microns (1mm)	
500	
250	
150	
75	
Neutralising value for the following particle sizes (µm):	
Passing through 75 microns	
Between 75 and 250 microns	
Between 250 and 1,000 microns	

ample magnesium in the subsurface layers of nearly all soils in NSW. The choice of a limestone, dolomite or magnesite for crops or pastures depends principally on price and to a lesser extent on the results of plant and soil testing and the crop type. In horticulture, dolomite or magnesite may be required to supply magnesium where it is shown to be deficient through soil or plant tissue testing. Chemical analysis of pure and commercial grades of the principal liming materials is given in Table 9.

Comparing liming materials

Information on the label will allow a comparison of the particle sizes and the neutralising value of liming products. A spreadsheet has been developed by some of the limestone crushers to assist in comparing liming products using this data. If the information specified under the Act is not available on a product, for example limestone from interstate, several laboratories are equipped to analyse limestone such as the Charles Sturt University Environmental and Analytical Laboratory at Wagga Wagga.

The quantity and timing of limestone application

Liming a paddock to achieve a surface soil (0 to 10 cm) pH_{Ca} of 5.2 will remove most of the problems associated with an acidic soil. If the 10–20 cm layer is also acidic then liming to pH_{Ca} greater than 5.5 will ensure a net movement of alkali down the profile.

Recommended liming rates based on a standard soil test are given in Table 11. As the results of the soil test are the average of many sub-samples it is likely that half of the paddock will have a pH_{Ca} and ECEC less than the average. Liming at a higher rate than that indicated in the table will ensure that this half of the paddock will receive sufficient lime to bring it up to the desired pH_{Ca}.

Liming to increase the pH_{Ca} of the surface 10 cm significantly above 6.0 should be avoided as it may induce deficiency of other plant nutrients such as zinc, boron and manganese in well weathered soils.

Where the soil is acidic to depth it may take many years for the lime effect to move to 20 cm, especially for heavy soils. Changes in pH_{Ca} in the subsurface soil layers of an acidic soil have been measured for 12 years in a trial to the east of Wagga Wagga. This trial has confirmed that if the pH_{Ca} is maintained around 5.5 in the top 10 cm then the pH_{Ca} at 15 to 20 cm will slowly increase.

Table 11 shows the amount of limestone required (fine and NV>95) to lift the pH of the top 10 cm of soil to 5.2 for a range of effective cation exchange capacities and pH normally encountered when making liming recommendations. The additional lime required to lift the pH from 5.2 to 5.5 is given in the right hand column. Assumptions: bulk density of soil is 1.4 and 70 per cent of the lime dissolves in one year. For cracking clays this table will give an over-estimate of lime required.

Timing of limestone application

Apply limestone before the most acid sensitive crop or pasture in a rotation as it gives the best economic return. If the limestone will not be effectively incorporated due to reduced tillage then apply the limestone a year before the most sensitive crop and apply it at a slightly heavier rate. These two actions will enhance lime movement into the top soil. The time of the year when lime is applied is not important. Limestone begins to become effective as soon as the soil is moist and reaches its major impact after 12 to 18 months.

Do not apply limestone directly before a wheat or triticale crop unless the root disease Take-all has been controlled with a break crop or grass-free long fallow.

Applying limestone to permanent pastures is often not economic as there is no incorporation of the limestone and the pasture species are generally acid tolerant and will give only a limited response. Where funds are limited, liming may not be a priority. However, delaying the liming program for too long will give more opportunity for the acidity to move deeper into the subsurface soil where it cannot be corrected. Always consider liming if a new pasture is being sown.

Check list before applying lime

The following list gives details to be checked to ensure that a response to liming is likely. This is particularly important when putting in a lime trial or test strip.

- The soil is acidic as determined using a soil test.
- The crop or pasture being limed is sensitive to acidity.
- The growth of crop or pasture is not restricted by some other factors such as poor soil structure, disease or a nutrient deficiency.
- The acidity of the subsurface soil will not restrict the productivity and persistence of the crop or pastures to be sown.
- The limestone to be used is sufficiently fine and with a high neutralising value, or is the most cost-effective product available.
- The lime rate is sufficient to correct the problem
- When planting wheat or triticale, Take-all has been controlled.
- The timeframe is long enough for top-dressed limestone to be effective.

Applying and incorporating lime

For the quickest and maximum effect, limestone should be finely crushed, evenly spread and incorporated into the soil to 10 cm.

Spreading machinery

Because agricultural limestone is generally fine and large quantities are usually applied, most spreading is done by contractors using 3–5 tonne hoppers and belt fed spinners or drop tubes (see photos 12 and 13). Combines and seeders cannot handle the quantity required per ha and conventional fertiliser spreaders have proved unreliable as the limestone tends to 'bridge' over the outlet.

Dust problems

Most limestone spreaders generate clouds of fine dust. This is the finest portion of limestone and, therefore, the quickest to react with the soil. Traditionally it has been claimed that up to 8% of the lime can be blown away. However, with the move to finer limestone this could be underestimating the problem. Many contract spreaders have a shroud to control the dust. Wetting the limestone with 2–4% by weight of water (400–800 L of water to 20 t of lime) minimises dust.

Table 11. Limestone required (fine and NV > 95) to lift the pH of the top 10 cm of soil to 5.2.

Colour codes group limestone rates to the nearest 0.5 t/ha

Soil test ECEC (meq/100 g)	Lime required (t/ha) to lift the pH of the top 10 cm:			
	from 4.0 to 5.2	from 4.3 to 5.2	from 4.7 to 5.2	from 5.2 to 5.5
1	1.6	0.8*	0.3*	0.2*
2	2.4	1.2	0.5*	0.4*
3	3.5	1.7	0.7	0.5*
4	3.9	2.1	0.9	0.6
5	4.7	2.5	1.1	0.7
6	5.5	3.0	1.2	0.8
7	6.3	3.3	1.4	1.0
8	7.1	3.8	1.6	1.1
9	7.9	4.2	1.8	1.2
10	8.7	4.6	1.9	1.3
15	12.5	6.7	2.8	1.9

*It is recognised that low rates of lime are impractical to apply, but over-liming can cause nutrient imbalances, particularly in these light soils.

KEY: Limestone rates per hectare

0.5 t/ha	1.0 t/ha	1.5 t/ha	2.0 t/ha	2.5 t/ha	3 to 4 t/ha	Split applications advised
🟧	🟦	🟥	🟩	🟨	🟦	🟪

Incorporation

Because limestone moves very slowly down through the soil, incorporation should be to the depth of the acidity problem (or as deep as practicable) for the most effective and speedy response (see photo 14).

Surface applied limestone

In sandy soils and where the annual average rainfall is greater than 600 mm, limestone applied to the surface may move to 10 cm depth in 2–3 years. As the clay content in the soil increases, or the rainfall decreases, there is less movement of limestone down the profile. A rapid response to surface applied limestone is most likely caused by release of molybdenum or improvement in legume nodulation, and the release of nitrogen from organic matter.

The effectiveness of surface applied limestone can be improved by the following techniques.

- Use of a fine grade of limestone spread when there is good ground cover will ensure that the limestone does not blow or wash away.
- Direct drilling after spreading limestone gives some incorporation.
- Use a superfine limestone, with a particle size as low as 70 microns. The smaller limestone particles wash down through a sandy or silty soil, achieving a distribution within the soil that is similar to the distribution that would have occurred if the limestone had been incorporated. Superfine limestone is mostly used in horticulture.
- Band limestone and superphosphate with the seed using direct seeding techniques. Only small amounts of limestone can be applied in this way.
- Certain species of earthworms also assist the movement of limestone into the soil; these worms may become available for purchase in the future.

ESTIMATING RATES OF SOIL ACIDIFICATION

It is possible to estimate the rate of acidification for a given paddock, enabling budgeting for future liming programs.

Rainfall is the climatic feature that has the greatest effect on the rate of soil acidification. It influences the following factors:

- plant productivity (which includes the amount of nitrogen fixed by legumes)

Photo 12: Lime spreading using drop tubes at Brungle.

Photo 13: Drop tubes for accurate lime placement.

Table 12. Management options for acid soils based on the pH (0–10) and pH (10–20). Soils with a pH above 5.6 do not have the problems associated with soil acidity.

pH: 0–10cm	pH: 10–20cm	Comments
5.0 to 5.5	5.0 to 5.5	Lime will increase Mo availability, reduce Mn availability and increase yield of only the **highly acid sensitive** plants (Table 6.)
≥ 5.0	< 5.0	Usually means lime has been applied to surface soil before.
< 4.7	≥ 5.0	Lime will increase yields of all **acid sensitive** crops and pastures.
<4.7	4.4 to 4.7	Lime will increase yields of all **acid sensitive** crops and pastures, but a dry finish to the season may reduce crop yields.
<4.7	3.9 to 4.3	Lime will increase yield of **acid tolerant** crops and pastures.

- leaching of nitrate nitrogen
- whether a pasture is predominantly annual or perennial.

These factors interact in their influence on the rate of acidification. For example, perennial plants use up most of the nitrate nitrogen before it can be leached, removing the main cause of soil acidification (see Table 3). It follows then that the highest rates of dryland acidification are in southern NSW in the 500–700 mm annual average rainfall zone, particularly under pastures based on annual legumes and grasses. In lower rainfall zones, acidification is limited by the lack of leaching of nitrate nitrogen. Perennial pastures are more likely to persist where rainfall is above 900 mm in the southern tablelands and slopes and above 700 mm in summer rainfall zones, and are able to take up most of the nitrate nitrogen that is produced before it can be leached.

Photo 14: Lime incorporation prior to sowing lucerne at Gundagai. Two workings will take place at right angles for maximum incorporation.

Table 13 shows some estimated acidification rates. The figures in the table apply to southern NSW based on a number of experiments. In other areas it will be necessary to seek out local data for an estimate of acidification.

FURTHER INFORMATION

For further information contact your district agronomist or horticulturist.

The following publications are also useful references:

Agfact P2.2.7, *Inoculating and pelleting pasture legume seeds*, NSW Agriculture

Winter cereal management guide, NSW Agriculture.

Soil acidity and plant growth, edited by A.D. Robson, Academic Press, Sydney.

NLWRA (2002) ‘Australians and natural resource management 2002.’ National Land and Water Resources Audit, Canberra.

The NSW Department of Primary Industries website contains much agricultural information: www.dpi.nsw.gov.au

Table 13: Examples of acidification rates for southern NSW used as a guide to calculate lime requirements.

Cause of acidification	**Rate of lime to neutralise acid added**
NO_3-N leaching[1] – District average	Average rate
High rainfall – annual crops or grasses	250 kg/ha/year
High rainfall – perennial crops and pastures	100 kg/ha/year
Medium rainfall – annual crops or grasses	150 kg/ha/year
Medium rainfall – perennial crops and pastures	50 kg/ha/year
Above average crop removal (See Table 2.)	
e.g. Soybeans	20 kg/t/ha/year
e.g. Corn silage	40 kg/t/ha/year
Above average fertiliser type (See Table1.)	
e.g. DAP	36 kg/100 kg DAP
Total annual lime requirement	sum of three categories above
Time to next liming if pH is above 5.0[2]	

[1] This rate will be based on local experimental data or if not available will need to be built up with farmer experience over time.

[2] If the pH < 5 it may be time to lime now. Experience in Wagga Wagga is that it is most economical to apply lime at 2 to 2.5 tonne per hectare when required to neutralise accumulated acidity, usually every 10 to 20 years.

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GLOSSARY

Acid soil	Soils that have a pH_{Ca} of 5.4 or less
Calcium chloride extractable aluminium and manganese	The aluminium and manganese measured in the 1:5 soil:0.01 M $CaCl^2$ extract used to determine pH_{Ca}. This is the aluminium and manganese that is immediately available to the plant.
Carbon cycle	The cycle of plants growing, producing carbon products through photosynthesis, dying, breaking down to organic matter and supplying nutrients to the next generation of plants.
Chlorosis	Abnormal yellowing of plants.
Effective cation exchange capacity (ECEC)	The sum of the values in a soil analysis of exchangeable cations (calcium, magnesium, sodium, potassium, manganese and aluminium). The unit of measurement is cmol(+)/kg (previously meq/100 g).
Electrical conductivity (EC)	EC is a measure of soil salinity, that is, concentration of soluble salts in the soil solution.
ESP –Exchangeable sodium percentage	Sodium on the exchange layer; calculated as exchangeable sodium divided by the sum of the exchangeable calcium, magnesium, sodium and potassium, expressed as a percentage.
Exchangeable cations	Exchangeable cations are positively charged ions that are loosely bound to negatively charged clay particles and organic matter in soil. The unit of measurement is cmol(+)/kg (previously meq/100 g).
Leaching	The percolation of water with dissolved nutrients through soil.
Lime	The name used to describe any of several liming materials, including agricultural limestone and dolomite. In the building industry "lime" refers to calcium hydroxide (slaked lime)
Necrosis	Death of parts of plants, giving a brown shrivelled appearance.
Nitrification	The transformation of ammonium to nitrate by microbes.
Nitrogen cycle	The cycle of plants taking up nitrogen, plants dying and releasing that nitrogen to the soil or air for the next generation of plants.
pH buffering capacity	The capacity of a soil to resist a change in pH when acid or lime is added to it.
Potentially available manganese	Manganese is held in a number of different ways in the soil, the most abundant being manganese oxide. Only some manganese is available to move into the soil solution when conditions are right and this manganese is referred to as potentially available.
Soil pH	Soil pH (Figure 3.) is measured in two ways in Australia. 1. Mixed and shaken 1:5 soil:0.01 M $CaCl_2$ (pH_{Ca}). 2. Mixed and shaken 1:5 soil:water (pH_w). pH_{Ca} gives pH values on average 0.5 to 0.8 lower, but with less seasonal variation, than pH_w. While most commercial soil testing laboratories use the $CaCl_2$ method, most field pH testing kits and some laboratories use the water method.

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