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Lime for high rainfall pastures: above 800mm average annual rainfall

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Lime for high rainfall pastures: above 800mm average annual rainfall



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Lime for high rainfall pastures: above 800 mm average annual rainfall

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Cover photographs: Ian Guthridge, on Matt and Sue Daubney farm near Northcliffe



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Soil acidification

Conventional agriculture acidifies soil. As your soil becomes more acid, productive pasture species disappear and are replaced by species of low agricultural value. It is a waste of money to apply expensive fertiliser to pastures which are inherently poorly productive because they are growing in an acid soil.

Soil acidification takes place via two major processes:

Product removal

Plants take up nutrients from soil solution as either positively charged cations (ammonium, sodium, potassium, calcium, magnesium) or as negatively charged anions (nitrate, chloride, phosphate, sulphate, borate, molybdate) and they usually take up more cations than anions.

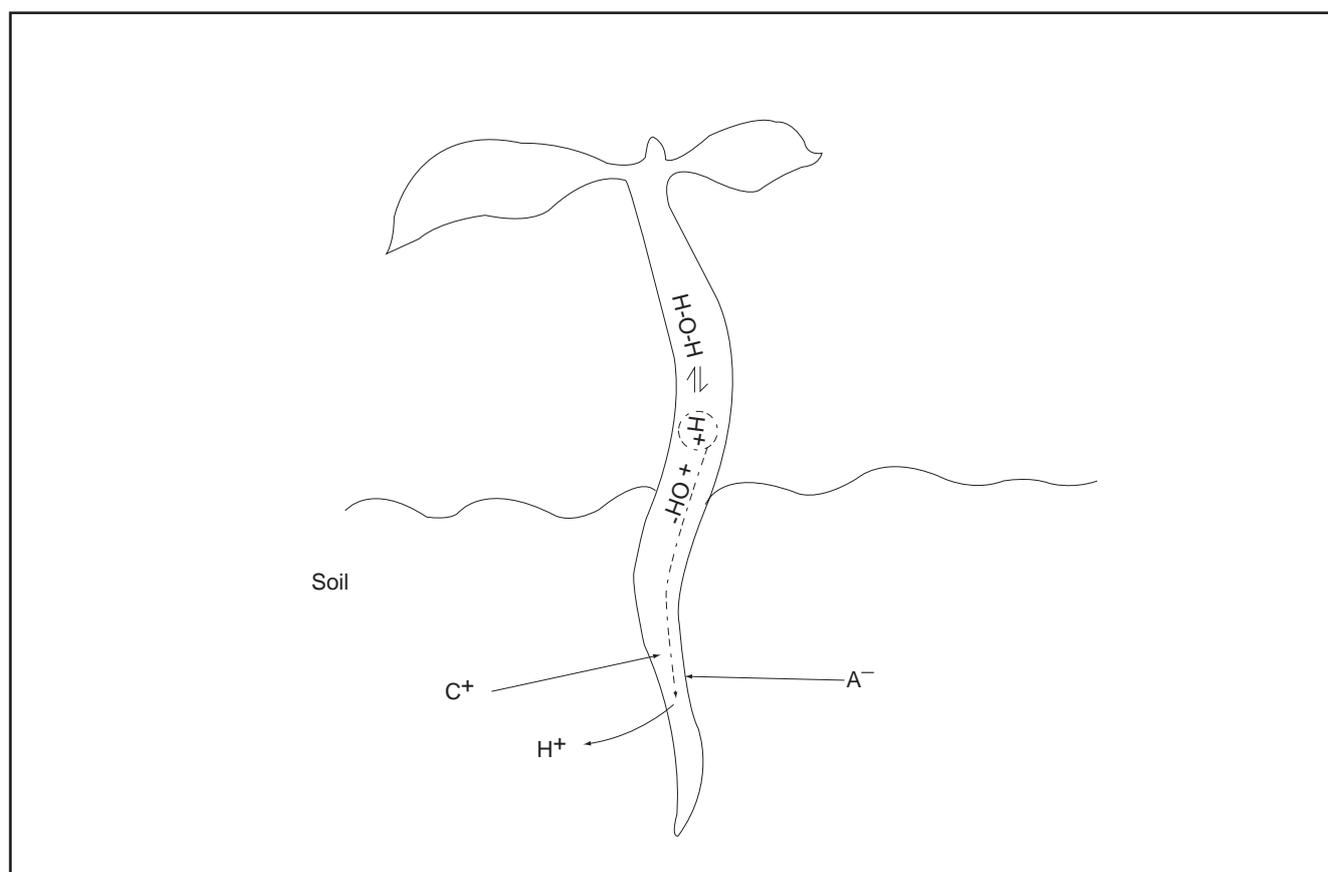
To maintain internal electrical neutrality, roots secrete hydrogen ions to balance the charge of the extra cations taken from soil. These hydrogen ions are produced from water in the roots dissociating into positive hydrogen ions (acidic) and negative hydroxide

ions (alkaline). This makes the adjacent soil more acid and the plant more alkaline—the source of ash alkalinity when plant residues are burnt.

The positive charge of the cations now in the roots is balanced by the negative hydroxide ions remaining in roots when water was dissociated to hydrogen ions and hydroxide ions.

The positive charge of hydrogen ions excreted from roots balances the negative charge of anions left in the soil when the extra cations are taken up.

If no product is removed from the paddock, there is no net loss of nutrients and acidification is negligible as plants break down to become soil organic matter. However, plants are removed as produce such as grain and fodder, or as animal products such as milk, meat, wool or hides. This acidifies soil because uptake of extra cations results in hydrogen ions being secreted into the soil. Alkali is generated in the plant and some of this alkali is removed when product is exported.



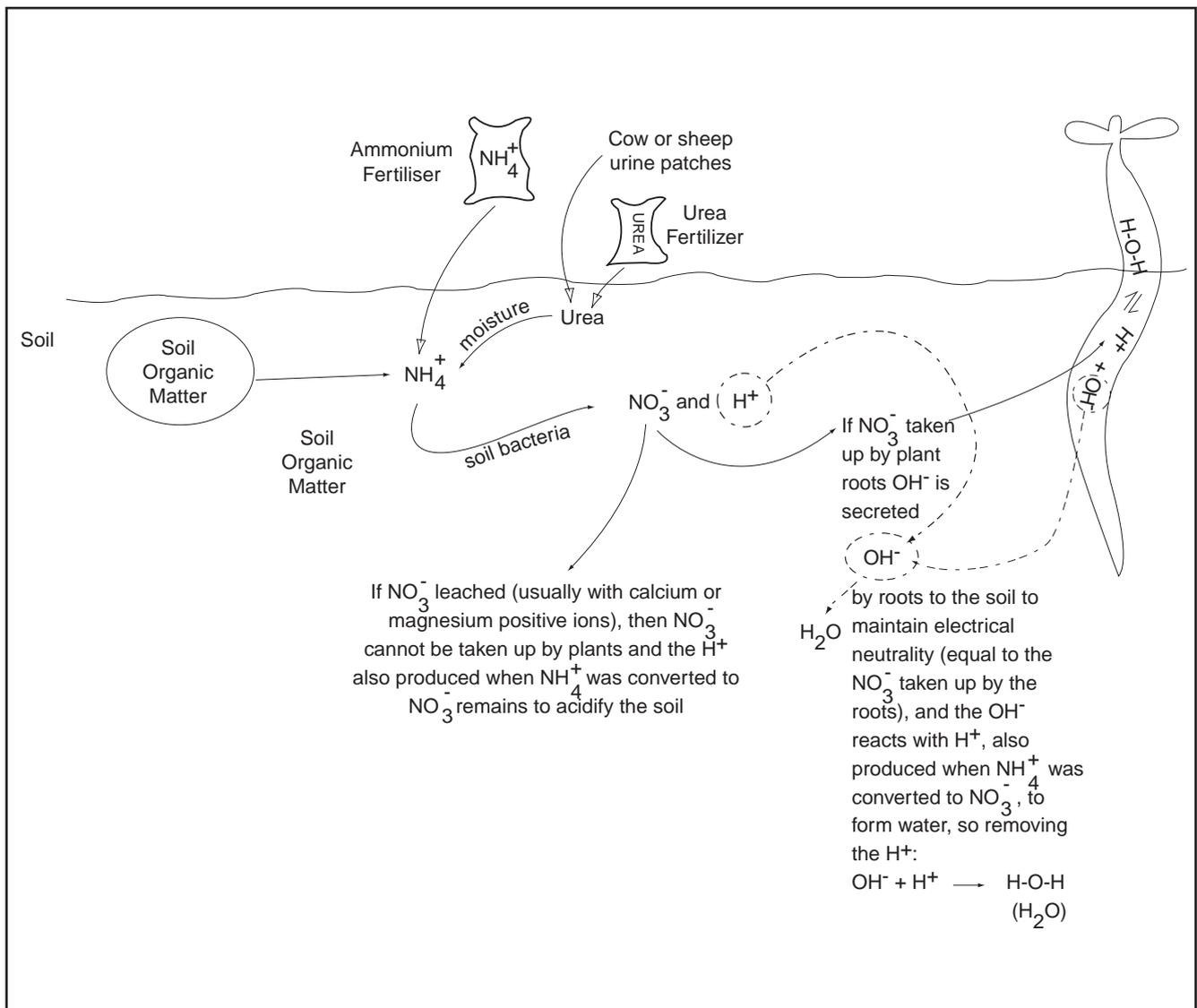
Diagrammatic presentation of the development of soil acidity due to product removal.

The nitrogen cycle

Plants and organisms which live in the soil—insects, earthworms, protozoa, algae, fungi and bacteria—break down and become part of the soil organic matter. Grazing animals also return organic matter to soil as faeces and urine.

Soil organic matter is a source of protein, energy and nutrients for plants and organisms growing in the soil. These organisms physically and chemically process soil organic matter to release some of its nutrients into soil solution, the process of mineralisation. Urea in urine patches is a source of nitrogen and potassium for both plants and soil organisms.

Plants take up nitrogen from soil as either ammonium or nitrate, and ammonium is among the first forms of nitrogen mineralised from soil organic matter. Ammonium is also added to soil as fertiliser (ammonium phosphates such as MAP and DAP, ammonium sulphate or ammonium nitrate). Urea, applied as fertiliser or in urine patches, is rapidly converted to ammonium. Ammonium is positively charged and soil constituents—organic matter, clays, oxides—possess both positive and negative surface charge sites. For most soils, the magnitude of the negative charge is much greater than that of the positive charge. Consequently, ammonium is usually retained by



Diagrammatic presentation for the development of soil acidity due to leaching of nitrate (NO_3^-) ions produced from ammonium ions (NH_4^+) derived from soil organic matter, or from urea and ammonium fertilisers, or from urine patches deposited by stock onto pasture while grazing.

negative charge sites and is not usually leached deeper into soil. In very sandy soils, with insufficient negative charge to retain all the ammonium mineralised from organic matter, or applied as fertiliser, some can be leached. In addition, the amount of ammonium and potassium present in urine patches can greatly exceed the capacity of soil to retain these elements, so both can be leached from urine patches.

When plant roots take up nitrogen from soil as positive ammonium ions, positive hydrogen ions produced from water in the roots are excreted to maintain electrical neutrality. This acidifies the soil. The hydroxide ions also produced remain in the plant and make it more alkaline (another source of ash alkalinity when plant residues are burnt).

Soil bacteria convert ammonium to nitrate and hydrogen ions. When plant roots take up nitrogen as negative nitrate ions, hydroxide ions derived from water in roots are secreted into the soil to maintain electrical neutrality. The hydrogen ions also produced remain in the plant and make it more acid. When hydroxide ions are released into the soil, they react with the hydrogen ions to produce water. Therefore, when ammonium ions are converted to nitrate and hydrogen ions, provided all the nitrate ions are taken up by plant roots, the hydroxide ions secreted in the uptake process consume the hydrogen ions and there is no net acidification of the soil. Sandy soils typically have negligible positive charge sites so nitrate ions are readily leached below plant rooting depth. When nitrate is leached, the hydrogen ions remain in the soil and acidify it. Because plants can only take up nitrogen as ammonium or nitrate ions, and ammonium ions are rapidly converted to nitrate ions, leaching of nitrate nitrogen is a major cause of soil acidification.

Why is soil acidification a problem?

The increased concentration of hydrogen ions in soil resulting from soil acidification:

- increases the dissolution of any manganese and aluminium in soil; this can induce manganese toxicity in plants and aluminium toxicity can affect growth of plant roots
- increases sorption of molybdenum by soil, inducing deficiency in plants
- is toxic to the Rhizobia bacteria required for symbiotic nitrogen fixation in legumes.

Manganese toxicity

In most agricultural areas, manganese toxicity is usually the first problem resulting from soil acidification. Below about pH 5.5, dissolution of manganese increases as the concentration of hydrogen ions increases. Plant roots take up soluble manganese from the soil solution. As the concentration of manganese increases, plants eventually take up toxic amounts, reducing yield.

Fortunately, the amount of manganese present in most agricultural soils in Western Australia is low. Though dissolution of manganese continues to increase as soils acidify, the amount of manganese dissolved is insufficient to cause toxicity for pastures.

Aluminium toxicity

Aluminium is a component of clays and oxides in soil, and aluminium compounds are present on the surfaces of many soil constituents. At soil pH greater than about 5.0, most aluminium is present in sparingly soluble form so there is negligible soluble aluminium in soil solution. However, as soil pH drops below 5.0, there is increased dissolution of aluminium.

Aluminium has no known role in plants but, when its concentration in soil solution exceeds about 20 mg per litre, it becomes toxic to plant roots. Aluminium toxicity greatly reduces root growth, reducing the ability of the roots to explore soil and take up water and nutrients.

Aluminium toxicity is the major soil acidity problem for agriculture in Western Australia.

Soil testing for aluminium

Although aluminium toxicity is the major soil acidity problem, no reliable soil test for aluminium has been developed, other than for the naturally very acidic sandplain Wodjil soils in the eastern agricultural region. Exchangeable soil aluminium is the best measure we have for estimating the potential for aluminium toxicity.

Exchangeable soil aluminium

The negative surface charge sites on soil constituents are balanced by cations from the soil solution. The **cation exchange capacity** of a soil is a measure of the amount of negative charge sites on the soil surface and is estimated by measuring the amount of cations balancing the negative sites.

Cation exchange sites are typically balanced by the major soil cations calcium, magnesium, potassium, sodium and, for acidified soils, hydrogen and aluminium. The amount of aluminium balancing negative charge, called **exchangeable aluminium**, is used as an indicator of when aluminium toxicity is likely to reduce plant yield.

The proportion of the major cations that balance the total cation exchange capacity of most productive soils is usually 65 to 80 per cent calcium, 10 to 20 per cent magnesium, 3 to 8 per cent potassium, less than 4 per cent sodium and less than 5 per cent aluminium.

If the proportion of aluminium on the soil exchange sites rises to over 30 per cent, aluminium toxicity is highly likely to affect production of even the most tolerant crop and pasture species.

Tolerance of subclover and ryegrass to aluminium toxicity

Subclover and annual and Italian ryegrasses, the major pasture species in our high rainfall pastures, are all relatively tolerant of aluminium toxicity. Aluminium toxicity becomes a major problem for these species when the soil pH falls below 4.3. For more sensitive species, such as lucerne and annual medics, aluminium toxicity becomes a major problem when the soil pH falls below 5.0.

Molybdenum deficiency

Plants require very small amounts of molybdenum and soils with pH values greater than 5.0 usually have enough indigenous molybdenum for pasture production. Very little molybdenum is sorbed by soil when the pH is greater than 5.0. However, as the pH of a soil drops below 5.0, its capacity to sorb molybdenum rises, inducing deficiency in pastures.

When land was newly cleared, molybdenum deficiency only occurred on naturally acidic soils and molybdenum fertiliser was applied. However, it is now realised that molybdenum deficiency is best ameliorated by applying sufficient lime to raise soil pH to greater than 5.0.

If too much molybdenum fertiliser is applied to pastures grazed by ruminants, the animals can develop molybdenosis.

Molybdenosis results from molybdenum reacting with sulphur and copper in the rumen to form a sparingly soluble compound. This prevents ruminants from taking

up sufficient copper from their gut and they become copper deficient. If they only have access to pastures with too much molybdenum, copper needs to be injected into the bloodstream. Alternatively, they must be moved regularly from pastures with the molybdenosis problem to pastures that do not have it.

It is nearly always better to lime a soil than apply molybdenum fertiliser.

Effect of soil pH on nitrogen fixation

The major pasture species for high rainfall pastures in Western Australia are the annual species subterranean clover (*Trifolium subterraneum*), annual ryegrass (*Lolium rigidum*) and Italian ryegrass (*Lolium multiflorum*).

Rhizobia bacteria in the soil infect the roots of emerging subclover plants to form nodules. In these nodules, the bacteria convert atmospheric nitrogen to nitrogen compounds required by the clover—mainly amino acids and proteins. This is biological nitrogen fixation. Ryegrass is a non-legume and cannot fix nitrogen. The dead remains of subclover plants—roots, stems, leaves, burrs and seed—are processed by soil organisms to release nitrogen to the soil, initially as ammonium ions. These are then converted by soil bacteria to nitrate and hydrogen ions, as previously discussed, to provide nitrogen for ryegrass.

The *Rhizobia* bacterium which infects subclover (*Rhizobia trifolii*) is more sensitive to low soil pH than the host plant; when the soil pH falls below about 4.5, the bacterial population declines. Eventually, nitrogen fixation cannot occur and clover has to obtain nitrogen from the soil. If there is insufficient soil nitrogen, nitrogen deficiency reduces clover and ryegrass production and persistence. Though fertiliser nitrogen can be applied to overcome nitrogen deficiency, aluminium toxicity greatly reduces the ability of roots to take up water and nutrients from the soil.

Measuring soil acidity

Soil pH is the most widely used and simplest method for assessing soil acidification and when to apply lime.

The pH of a solution is the negative logarithm of its hydrogen ion concentration. As the concentration of hydrogen ions increases, pH values decline.

Soil pH was traditionally measured in a suspension of 1 weight of soil to 5 volumes of water. However, the salt content of the soil has an influence on soil pH measured by this method. If salt is added to a soil-water suspension, the pH decreases. To overcome this problem, a salt solution of 0.01 molar calcium chloride is now used instead of water. All pH values quoted in this Bulletin were measured in calcium chloride—pH[CaCl₂].

The standard depth used in Western Australia when sampling for soil nutrients and acidity is 10 cm. If subsurface acidity is considered important, samples should also be collected from 10–20 cm and from 30–40 cm.

Subsoil acidity

Research in the cropping areas of south-western Australia has shown that the decline in soil pH since the start of agriculture is often greater in the subsoil than in surface soil, with the greatest decline from about 10–40 cm depth.

Extensive research in eastern Australia has shown that subsurface acidity is a major problem for high rainfall pastures in that region.

Until the mid 1990s, there was little evidence for subsurface acidity in the high rainfall areas of Western Australia, probably because these areas were developed much more recently than the high rainfall pastures in eastern Australia. However, since the early 2000s, there is increasing local evidence for subsurface acidity in high rainfall pastures, particularly where surface soil pH has been allowed to decline to 4.0 or less. Whether or not a low subsurface pH reduces the productivity of our generally shallow-rooted pastures has yet to be determined.

Subsurface acidity is much more difficult and costly to ameliorate than topsoil acidity.

Ameliorating soil acidity

The simplest way to ameliorate soil acidification is to add lime to the soil. When lime is added to moist soil, alkali dissolves from the lime and consumes hydrogen ions. The lime can be left on the soil surface, incorporated into the surface 2 cm using heavy harrows or disced into the surface 10 cm. Generally speaking, the lower the surface pH, the more necessary incorporation becomes.

Sources and rates of lime are discussed in a subsequent section.

Ameliorating subsurface acidity

If the pH in the 10–20 cm and 20–30 cm zones is less than 5.0, subsurface acidity may be a problem. The only practical way to raise the subsurface pH is to apply sufficient lime to raise the pH of the top 10 cm of soil to 5.5 or greater. When the pH of the top soil is above 5.5, the alkali dissolved from the lime moves rapidly into the subsoil.

If the surface soil pH is maintained above about 5.5, subsurface acidity should not be an issue.

Sources of lime

There are three sources of agricultural lime in Western Australia:

- Limestone
- Limesand
- Dolomite

Limestone (calcium carbonate) is the most common lime source south of Perth; it is found naturally as rock and needs to be crushed to be effective.

Limesand (calcium carbonate) is mostly found north of Perth and occurs as sand dune deposits. Unlike limestone, limesand is not usually ground before application because much of it exists as fine, porous, sand-grain sized material.

Dolomite is a mixture of calcium and magnesium carbonates, with most deposits usually comprising about 60 per cent calcium carbonate and 40 per cent magnesium carbonate. It occurs naturally near salt lakes in the cropping areas of the south-west. Dolomite often contains large rocks so is usually ground before application. Because dolomite deposits are usually a long way from high rainfall areas, high transport costs result in dolomite being more expensive than limestone or limesand.

Although magnesium deficiency has not been detected in pastures in Western Australia, dolomite is often recommended to increase soil magnesium levels. To ensure magnesium deficiency does not occur in animals, they can be supplemented directly.



Loading limesand. Photo: David Gartner

Lime quality

Lime quality is now evaluated by **effective neutralising value** (ENV). ENV is a lime quality testing and reporting procedure that has replaced neutralising value (NV) and particle size previously used. It is a measure of the ability of a lime source to neutralise (ameliorate) soil acidity.

The NV of a lime source is compared to the NV of pure calcium carbonate which is defined as 100 per cent. If a lime source has a NV value of 80 per cent, then it is 80 per cent as effective as pure calcium carbonate at reducing soil acidity. Most lime sources in Western Australia have NV values of 60 per cent to 90 per cent, with the best deposits having NV values of 90 per cent or more.

A lime source with fine particles has a greater surface area exposed to the acid (hydrogen ions) in the soil and will neutralise soil acidity faster than coarser lime particles. The carbonate component of lime exposed at the surface of lime particles reacts with hydrogen ions in soil solution or on the surfaces of soil constituents. The greater the number of carbonate ions exposed at the surface of lime particles, achieved by using finer lime particles, the quicker soil pH is increased.

In the past, NV was considered the major factor that determined the ability of a lime source to reduce soil acidity. Recent research has shown that over 70 per cent of the effectiveness of a lime product in ameliorating soil acidity can be explained by particle size, whereas less than 10 per cent can be explained by NV.

ENV considers NV, particle size and two other factors.

One factor measures changes in soil pH due to the lime source. This is a laboratory test carried out by mixing a given amount of lime with a given amount of soil, adding water to the mixture and measuring soil pH after the moist mixture has been incubated for a set length of time. In another sample of the same soil, the same procedure is repeated but no lime is applied. From the two samples, the change in soil pH due to adding lime to the soil can be calculated.

The second factor is to measure the solubility (dissolution) of the different size fractions of the lime source. To measure lime dissolution, the lime

sample is separated by sieving into five fractions: 0 to 0.125 mm, 0.125 to 0.5 mm, 0.5 to 0.75 mm, 0.75 to 1.0 mm, and greater than 1 mm. The percentage of particles that pass through each sieve is recorded. The solubility of lime in the different sieved fractions is then determined.

The combination of all three factors (sieve analysis, NV and soil pH changes) determines the ENV which is expressed as a percentage. The higher the ENV percentage, the more effective is the lime source at increasing soil pH.

How much lime to apply

There is no simple answer to the question of how much lime is required to achieve a pH of 5.5 or greater in the top 10 cm of soil. The amount depends on many factors, particularly on how low the pH is currently.

Amelioration of soil acidity depends on a chemical reaction between the lime and the soil. Because of this, the properties of both soil and lime determine the amount of lime required. Dissolution of lime takes place in moist soil, so rainfall is important. Other climatic factors, such as temperature and humidity, also influence the reaction between soil and lime. Factors that determine the amount of lime required include:

- **The soil pH:** for any given soil and lime source, more lime is required to raise soil pH the lower the soil pH is to start with.
- **The pH buffering capacity** of the soil, which is the capacity of the soil to retain hydrogen ions. This in turn is largely determined by the amount of clay, iron and aluminium oxides, and organic matter in the soil. The larger the pH buffering capacity, the more lime is required to increase soil pH.
- **The bulk density** of the soil (mass of soil per unit volume). Soils with more pore space relative to mass of soil particles have lower bulk densities and so need less lime, while soils with larger bulk densities have larger mass of soil per unit volume and so require greater amounts of lime.
- **The amount of lateritic ironstone gravel stones**, which are particles of greater than 2 mm diameter, in the soil. Gravel particles have little impact on soil chemical properties but do influence soil mass and bulk density. Many sandy gravel soils in Western Australia contain more than 60 per cent gravel. These relatively chemically inert gravel stones decrease the amount of lime required per volume of soil to raise soil pH.
- **ENV** determines the ability of the lime source to increase soil pH. ENV depends on the NV and particle size of the lime source used, how soluble different size fractions of the lime are in the soil and the magnitude of the increase in soil pH due to adding the lime source to the soil.
- **The speed** at which lime dissolves in the soil to consume hydrogen ions, and the speed at which it moves down the soil to ameliorate subsoil acidity,

depends on soil moisture, including rainfall, soil temperature and humidity. The longer the lime is in moist, warm soil, the more rapidly the lime reduces soil acidity.

- **Depth** of incorporation of lime into the soil.

To cope with these varying factors, general recommendations are given for the typical amount of lime to apply to raise soil pH. For example, if the soil pH is 4.2 and the lime source has a ENV of greater than 80 per cent, between 2 and 4 tonnes of lime per hectare is usually recommended for sandy soils, and between 4 and 7 tonnes per hectare for loam and clay soils.

If the surface soil pH is 4.0 or below, several applications of lime may be required to raise the pH to 5.5. Once this pH has been achieved, movement of lime from the topsoil to the subsoil becomes rapid.

Other important factors to consider

Pasture renovation

Clover and ryegrass are our most productive pasture species but soil acidification can lead to pastures becoming dominated by poorly productive species, reducing animal production. Therefore, once liming has started, the pasture often needs to be renovated by oversowing with clover and ryegrass.

Grazing management

Grazing management is the key to high pasture use and high pasture use is the basis of profitable grazing industries. Good grazing management also helps maintain good pasture composition. Once low soil pH has been corrected and the pasture renovated, it becomes possible to improve grazing management to use as much paddock-grown feed as possible.

More information about grazing management can be found in a number of publications on the DAFWA website www.agric.wa.gov.au

Fertiliser

Pastures growing in low pH soils are usually dominated by poorly producing pasture species so it is a waste of money to apply fertiliser to these pastures. It is also a waste of money to fertilise under-grazed pastures to grow more unused feed. It is only profitable to apply fertiliser to productive pastures that are managed to maintain high pasture use.





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