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Soil acidity : a guide for WA farmers and consultants

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Soil acidity

A guide for WA farmers and consultants



PART 2

Chemistry and biology of soil acidity



Soil pH

pH scale

Soil pH is used to indicate the acidity (or alkalinity) of soil, and is a measure of the concentration of hydrogen ions (H^+) in the soil solution. pH is measured from 1 (acidic) to 14 (alkaline), with 7 being neutral (Figure 25) on a negative logarithmic scale (base 10).

Because of the logarithmic scale, soil with a pH of 4 is 10 times more acidic than a soil with a pH of 5 and 100 times more acidic than a soil with a pH of 6. This means that a small decrease in soil pH results in a large increase in acidity. For example, there is 2.5 times more acid at pH 4.4 than at pH 4.8 (Figure 26).

Soil pH buffering

The buffering capacity of a soil indicates the capacity of the soil to resist pH change. Soils differ in their buffering capacity. Soils with a high proportion of clay or organic matter have a larger number of surface sites able to accommodate hydrogen ions and can hold larger numbers of the hydrogen ions before they increase in the soil solution. Once acidic, however, these soils are able to release hydrogen ions into the soil solution to maintain equilibrium and resist increase in pH. Clays are generally better buffered than loams, which in turn are better buffered than sands. Better buffered soils are slower to acidify but require more lime to lift pH when they do acidify. The naturally acidic peaty sands of the south coast have a high buffering capacity and would require more lime to increase pH than other wheatbelt soils.

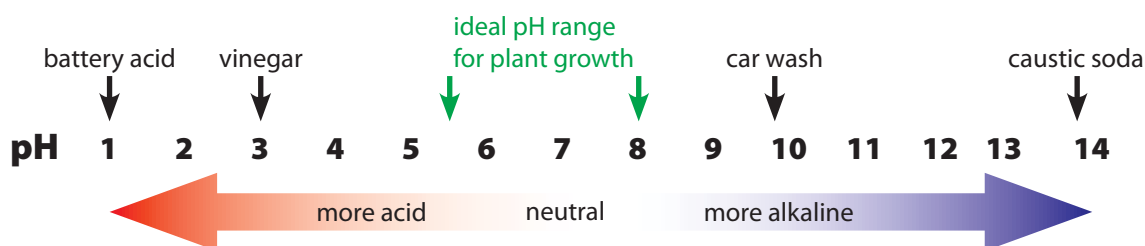


Figure 25 Examples of where common substances fit on the pH scale

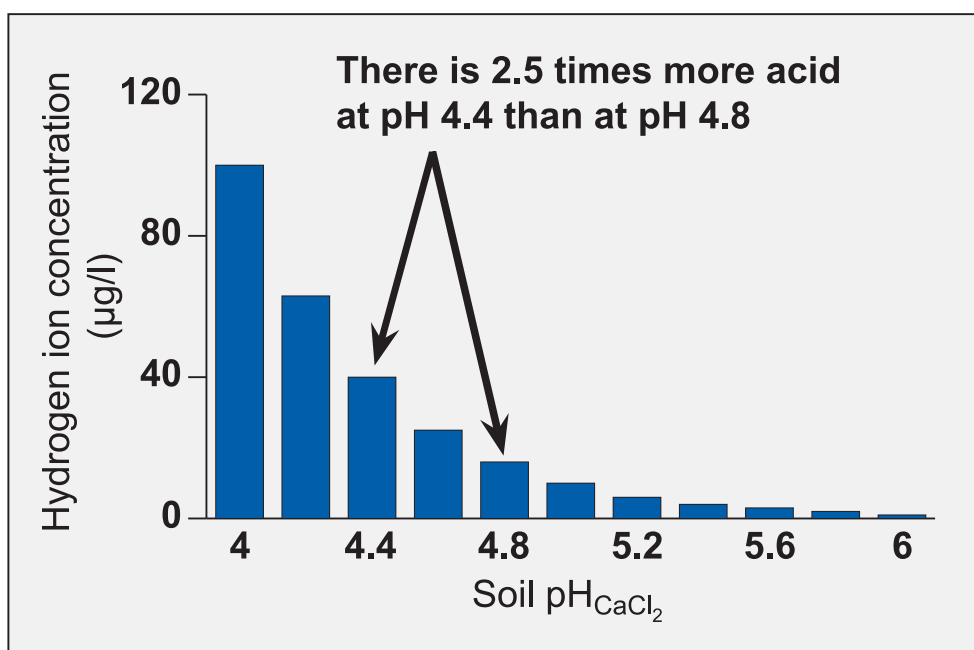


Figure 26 A small decrease in soil pH from 4.8 to 4.4 results in a 2.5 times increase in acidity because of the logarithmic relationship between pH and hydrogen ion concentration.

Measurement of pH

The most accurate method of soil pH measurement will be achieved in a professional laboratory (Figure 27). The Australasian Soil and Plant Analysis Council Inc. can provide a list of accredited laboratories. The accepted standard technique is to measure the pH of soil in a weak solution of calcium chloride (CaCl_2). A ratio of 1 part soil to five parts 0.01 M CaCl_2 is used. This method overcomes the problems of seasonal variation in soil pH when measured in water, especially in soils with low total salts. Soils vary in the concentration of salts (for example, calcium, magnesium, sodium and potassium chlorides, nitrates and sulfates). The concentration of salts also varies as the moisture content of the soil varies. The impact of these variations on pH is minimised when measured in 0.01 M calcium chloride. Soil pH measured in water can be 0.6 to 1.2 pH units higher than in calcium chloride (Figure 28). If conversion is necessary, 0.7 is usually deducted from the water value. In this guide, all references to soil pH are measured in calcium chloride.

Appropriate sampling of soil for pH testing is vital for meaningful results (see soil sampling, page 4).

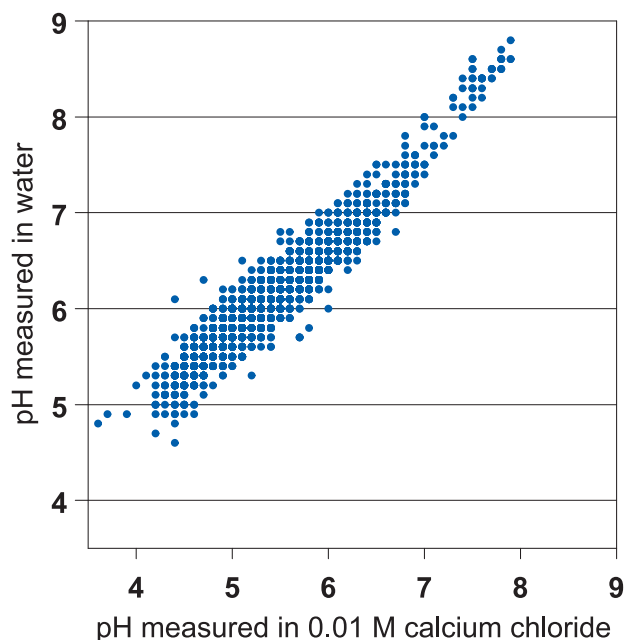


Figure 28 **Comparison between pH measured 1:5 soil:water and pH measured 1:5 soil:0.01 M calcium chloride for WA wheatbelt soils**



Figure 27 **The most accurate pH measurements will be achieved in a commercial laboratory. Photo: CSBP**

Effects of soil acidity

In WA, the major problem when soils acidify is aluminium toxicity in the subsurface soil. Low pH in topsoils primarily affects nutrient availability and decreases nodulation of legumes and nitrogen fixation in pastures. These problems are minimised if the topsoil pH is maintained above 5.5.

Aluminium toxicity

Aluminium is present in soils in a variety of forms and bound to the soil constituents, particularly clay particles and organic matter. When soil pH drops, aluminium becomes soluble and the amount of aluminium in the soil solution increases. As a rule of thumb, soil aluminium concentration between 2 and 5 ppm (mg/kg) is toxic to the roots of sensitive plant species, and above 5 ppm is toxic to tolerant species.

In most wheatbelt soils, aluminium will reach toxic levels when subsurface pH falls below 4.8. Generally, there is sufficient organic matter in topsoil so that aluminium can remain bound

and does not become toxic to plant roots even though it is extractable in laboratory analysis.

Toxic levels of aluminium in the soil solution affect root cell division and the ability of the root to elongate (Figure 29). The root tips are deformed and brittle (Figure 30). Root growth and branching is reduced. Poor crop and pasture growth, yield reduction and smaller grain size occur as a result of inadequate water and nutrition. The effects of aluminium toxicity are most noticeable in seasons with a dry finish. Roots are unable to effectively grow through acidic subsurface soil which forms a barrier and restricts access to stored subsoil water for grain filling.

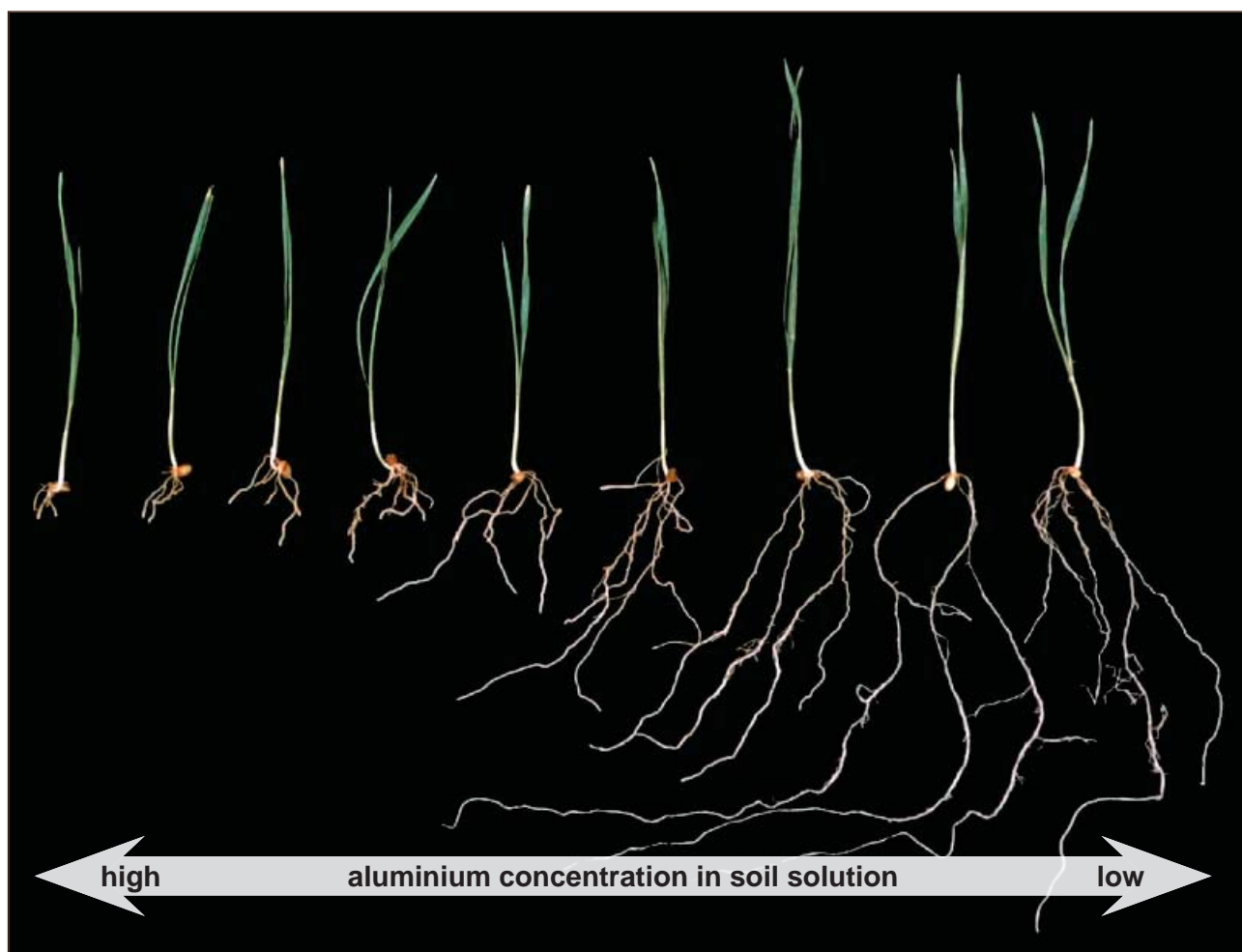


Figure 29 Wheat seedlings grown in soil with a range of aluminium concentrations. Photo: S Carr

Effects of soil acidity

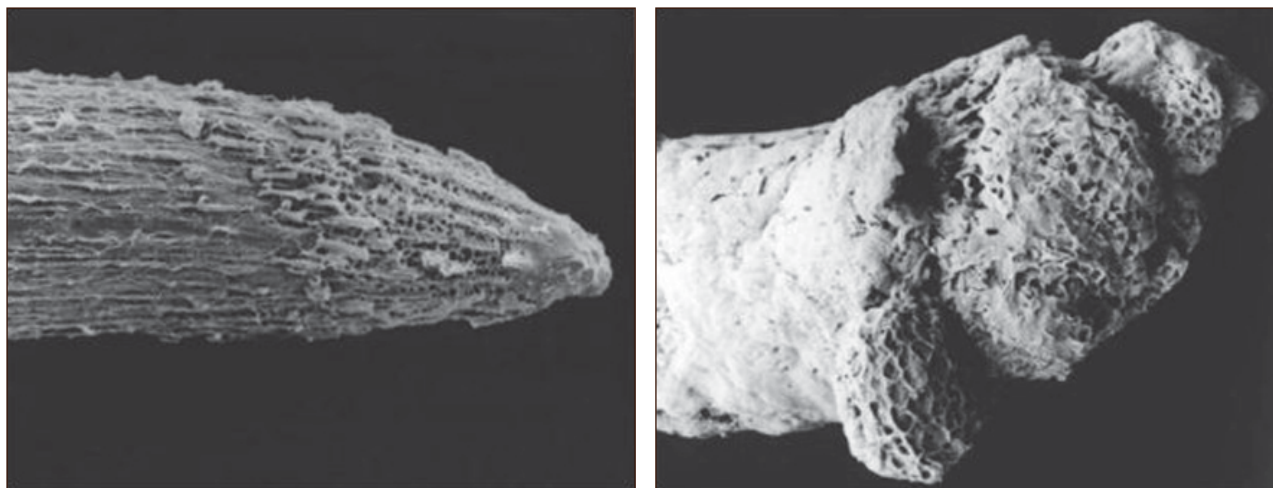


Figure 30 **Healthy root tip (left) compared to a root tip affected by aluminium toxicity (right).** Photos: CSIRO

Liming soil to increase the soil pH is effective in reducing the availability of aluminium to non-toxic levels. Figure 31 shows 11-day old barley seedlings grown in acidic subsurface soil. The seedlings on the left were grown in soil that was limed to increase pH to 5.1; aluminium concentration < 2 ppm. The seedlings on the right were grown in the same soil without lime at a pH of 4; aluminium concentration 15 ppm.

Measurement of soil aluminium

The measurement of aluminium in the soil solution is complicated and is affected by many factors. Depending on the methods used it is

not always possible to distinguish between toxic and non-toxic forms of aluminium. A rough guide to the levels of aluminium can be achieved by measuring aluminium concentration in the same 0.01 M CaCl_2 solution used to measure the soil pH. The measurement of aluminium in topsoil is further complicated by the presence of higher levels of organic matter because aluminium can be bound to the organic matter (and therefore in a non-toxic form) but is released when extracted with the 0.01 M CaCl_2 solution. In most cases, the subsurface soil pH will be a good indicator of toxic aluminium levels.



Figure 31 **Barley seedlings grown in limed (left) and unlimed (right) acidic subsurface soil**

Effects of soil acidity

Nutrient availability

The availability of nutrients to plants is altered by soil pH (Figure 32). In acidic soils, the availability of the major plant nutrients nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum is reduced and may be insufficient. Liming to raise the pH of acidic soil will increase the availability of these nutrients.

The availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In WA, toxic levels of aluminium is usually the only problem, as discussed above. Manganese toxicity can occur in acidic soil in the eastern states of Australia. However, concentrations are rarely high enough in WA wheatbelt soils to be toxic even at low soil pH.

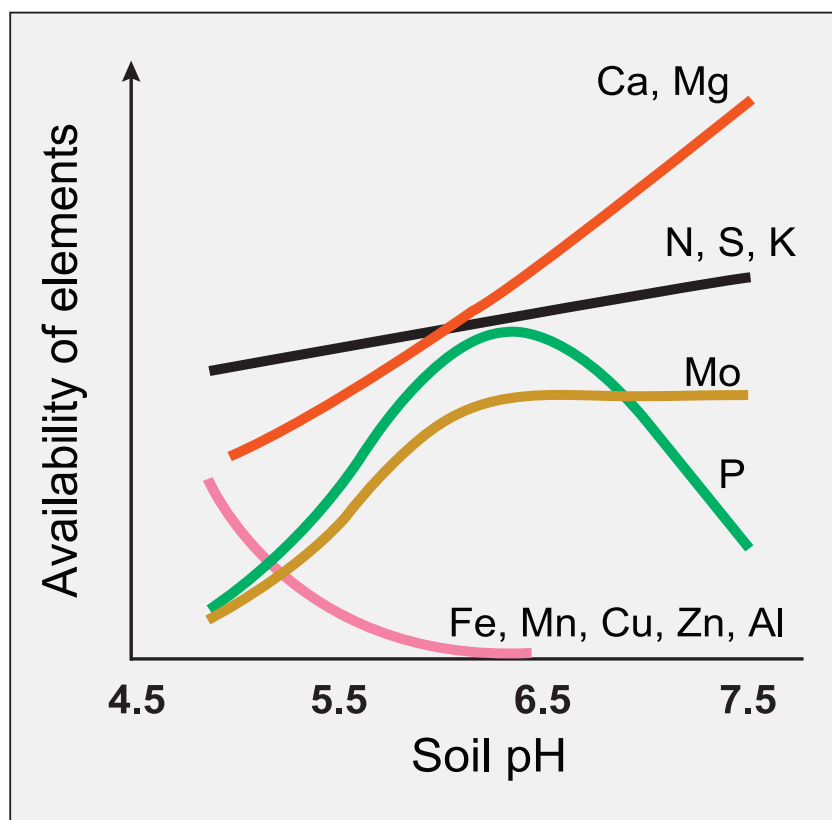


Figure 32 Relationship between soil pH and nutrient availability. In acidic soils, some nutrients may be insufficiently available for optimal plant growth and aluminium may become toxic.

Effects of soil acidity

Soil microbial activity

Most microbial processes are reduced in acidic soil because growth and reproduction of the soil microbes, primarily bacteria and fungi, are reduced. Breakdown of organic matter and cycling of nutrients is reduced. The rate of mineralisation of nutrients by soil microbes into plant-available forms is slower, potentially limiting plant uptake. Most importantly, legume nodulation can fail. Under favourable conditions, nitrogen-fixing rhizobia bacteria form

a symbiosis with crop and pasture legumes in root nodules (Figure 33). In acidic soils, rhizobia bacteria may be unable—or populations too low—to form a functioning symbiosis, resulting in nitrogen deficiency. Species of rhizobia bacteria vary in their tolerance to soil acidity, for example, medic rhizobia are very sensitive and may fail to persist. Grass-dominated pastures can result from the failure of pasture legumes to thrive in acidic soil.



Figure 33 Well nodulated (left) compared to poorly nodulated subclover plants. Photo: Centre for Rhizobium Studies, Murdoch University

Causes of soil acidity

Soil acidification occurs naturally very slowly as soil is weathered but is accelerated by productive agriculture. Soil acidifies because the concentration of hydrogen ions in the soil increases. In WA, the two main causes of soil acidification are inefficient use of nitrogen and export of food and fibre from the farm.

Nitrate leaching

Nitrogen in agricultural systems may be fixed from the atmosphere by legumes, decomposed from soil organic matter (the dead remains of plants and animals) by soil organisms, or added in various types of fertilisers. Different nitrogen fertilisers follow slightly different chemical pathways as they break down in the soil and contribute different amounts of hydrogen ions (acid) to the soil. Fertiliser nitrogen that enters and leaves the system in the same form does not contribute to soil acidification—for example, potassium nitrate. Ammonium-based fertilisers are the major contributors to soil acidification and this is increased by leaching.

Ammonium nitrogen from fertiliser or soil organic matter is readily converted to nitrate and hydrogen ions by bacteria in the soil. Different amounts of hydrogen ions are contributed to the soil, depending on the fertiliser. If nitrate is not taken up by plants, it can leach away from the root zone. Nitrate ions

are readily leached from most WA agricultural soils because there are more negatively charged surface sites on soil constituents (required to retain the negatively charged nitrate ions) than positively charged surface sites. If nitrate leaches, a positively charged cation is also leached to maintain electrical balance. The cations that leach are usually sodium, potassium or calcium because hydrogen ions are more strongly held by the soil. The result is a net increase in hydrogen ions.

If a negatively charged nitrate ion is taken up by plant roots, a negatively charged hydroxide ion is excreted to maintain the electrical balance. The hydroxide ion combines with a hydrogen ion in the soil to form water (the hydrogen ion is no longer contributing to soil acidity). If the nitrate ion taken up by the plant was from potassium nitrate, there would be a liming effect because no hydrogen ions were contributed to the soil with the fertiliser. If this nitrate ion leached, there would be no liming effect, but also no soil acidification (Figure 34).

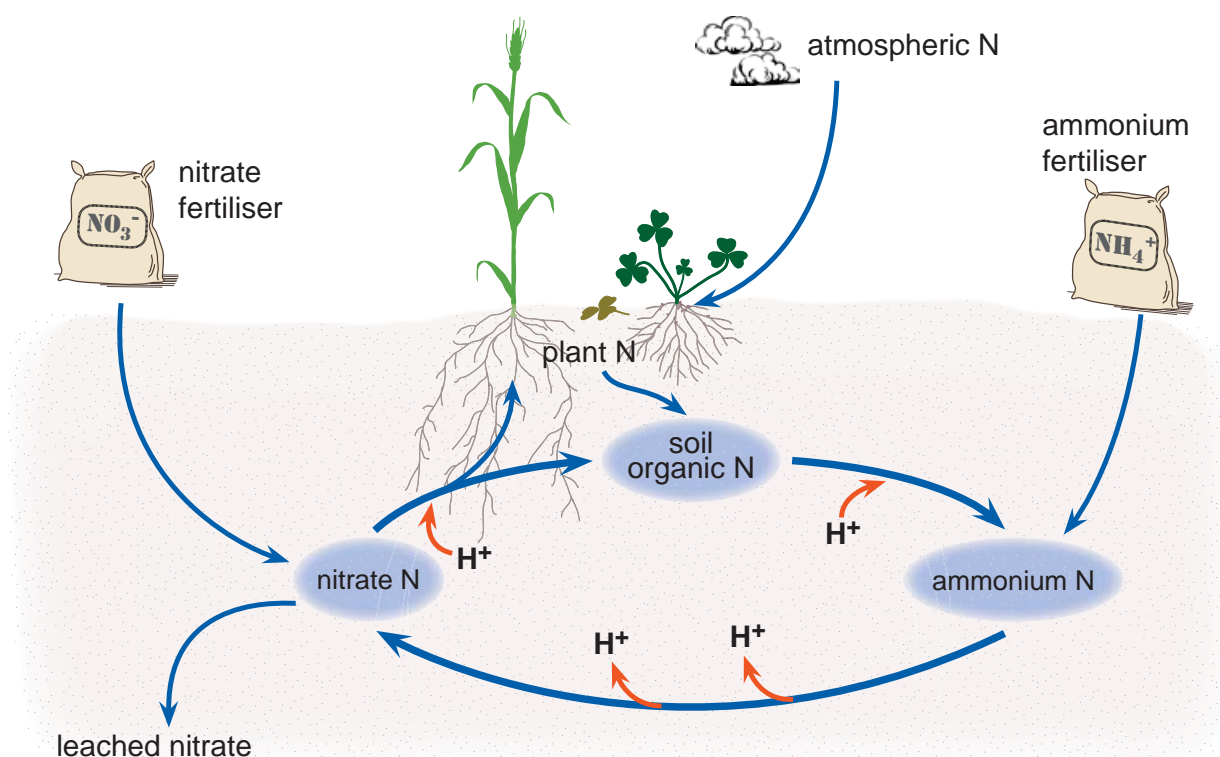


Figure 34 The main pathways showing the involvement of nitrogen (N) fertilisers in soil acidification

Causes of soil acidity

Export of produce

Most plant material is slightly alkaline. Plant roots take up nutrients as either cations, which are positively charged (for example, ammonium, potassium, calcium or magnesium) or as anions, which are negatively charged (for example, nitrate, phosphate or sulfate). Plants absorb more cations than anions and each time a positively charged cation is absorbed by the plant, a positively charged hydrogen ion must be excreted into the soil to maintain electrical balance.

If plant material is removed by grazing or harvest (Figure 35) or relocated by the concentration of dung into stock camps, rather than being returned to the soil, there is a net export of alkalinity and residual hydrogen ions remain in the soil. Over time, as this process is repeated, the soil becomes acidic. A translocation of alkalinity can occur in windrows with the soil off the windrow becoming more acidic.



Figure 35 Harvesting wheat at Maya. Soil acidity is an inevitable part of productive farming; removal of produce contributes to soil acidification.

PART 3

Agricultural lime guide



Lime sources

Agricultural lime is any product that is used to increase the pH of soil. In WA, the three main sources are limesand, limestone and dolomitic lime. Application of one of these products is usually the most economical method of ameliorating soil acidity.

Limesand

Limesand is mined from coastal sand dunes found in various places along the south-west coast (Figures 36 and 37). It is entirely different from the silica sand that is found on beaches around Perth. Limesand is comprised mostly of shell and coral fragments from marine organisms—predominantly calcium carbonate with some magnesium carbonate. The limesand dunes, which are approximately 10 000 years old, were formed by wind action when sea levels dropped and the exposed limesand was moved inland. The fineness, types of shell and purity varies between deposits.



Figure 37 Close-up of agricultural limesand from pit near Dongara



Figure 36 Limesand mine near Dongara

Limestone

Most limestone for agriculture is mined and crushed from coastal deposits of Tamala limestone (Figures 38 and 39). This limestone is 1–2 million years old and was formed by cementation of limesand deposits, either by the action of rainfall wetting and drying or when the deposits were submerged during periods of high sea level. The composition and purity of limestone also varies between deposits.



Figure 39 Close-up of agricultural limestone from pit near Myalup



Figure 38 Limestone mine near Myalup

Dolomitic lime

(usually marketed as dolomite)

Dolomitic lime in WA is mostly mined from old lake and inland drainage systems (Figures 40 and 41). Dolomitic lime has a higher proportion of magnesium carbonate than limesand or limestone. It was formed by the accumulation of calcium and magnesium carbonates dissolved from rock.



Figure 41 Close-up of dolomitic lime from pit near Watheroo



Figure 40 Dolomitic lime mine near Watheroo

Other liming products

Other types of agricultural lime which may be used include Cretaceous chalk and lake bed marls. Industrial by-products from cement manufacture and lime kiln dust may be available.

As for all agricultural limes, the quality and value of these products should be assessed before use (see [Lime quality](#), page 35).

Calcium oxide (burnt lime or quicklime) and calcium hydroxide (slaked or hydrated lime) are not recommended for use as agricultural lime. Storage and handling is difficult; they are caustic so skin contact and inhalation need to be avoided and burnt lime reverts to calcium carbonate if stored exposed to air.

Lime quality

The key indicators of agricultural lime quality are neutralising value and particle size, regardless of the source. While the quality of agricultural limes can vary widely, high-quality lime is available from limesand, limestone and dolomitic lime sources.

How lime works

Excess hydrogen ions in the soil solution cause soil acidity. When agricultural lime is applied, carbonate from calcium carbonate (or magnesium carbonate) neutralises acid in the soil (Figure 42). The soil chemistry can be simplified into a few steps: in wet soil calcium carbonate ionises (separates) into calcium and carbonate ions; the carbonate reacts with water to form bicarbonate ions; the bicarbonate ions react with hydrogen ions in the soil solution to form carbon dioxide and water. The hydrogen ions that were contributing to soil acidity are now chemically bound in water and soil pH increases.

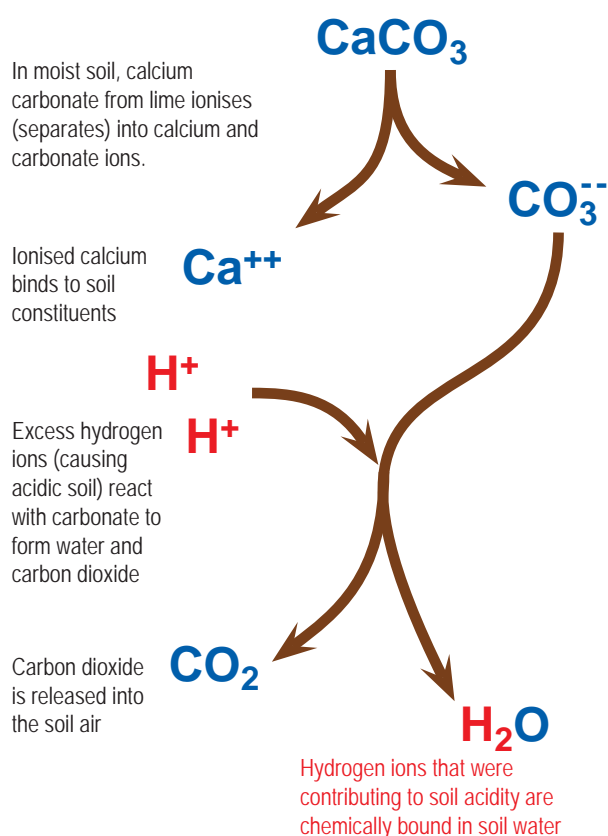


Figure 42 Simplified representation of how lime reacts in soil to treat acidity. There are more-complicated chemical steps in this pathway, but the end result is that the soil has more calcium ions on the exchange surface, carbon dioxide is released into the soil air and hydrogen ions that were contributing to acidity are bound in soil water.

Neutralising value

The carbonate content of limesand, limestone or dolomitic lime determines the capacity of the lime to neutralise acidity. Neutralising value is expressed as a percentage relative to pure calcium carbonate, which is given a value of 100 per cent. With higher neutralising value, lime can be spread over a greater area, or less used, for the same pH change (Figure 43).

Agricultural lime suppliers should provide results of current laboratory tests detailing the neutralising value (sometimes expressed as NV) of the various particle sizes in their product. These values can be used to calculate the best value lime available.

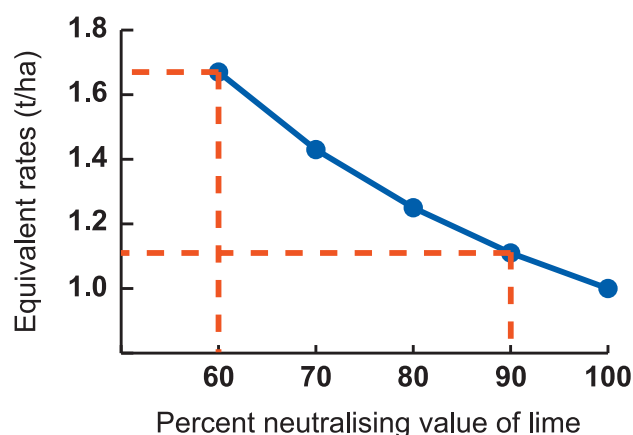


Figure 43 Lime required to apply the equivalent neutralising capacity for agricultural limes of differing neutralising value

Lime quality

Particle size

The size of the lime particles determines how quickly the lime can neutralise acid. Lime with a higher proportion of finer particles has a larger surface area to react with the acid in the soil. Research shows that finer limes increase pH faster (Figure 44), which is necessary for rapid amelioration of acidic soil.

Suppliers of limestone and dolomitic lime crush and screen their products and suppliers of limesand may screen to remove vegetation if necessary. This processing ensures supply of a consistent product. Suppliers should provide details of the particle size distribution of their product. Farmers should ensure that products contain an adequate proportion of fine particles to meet their needs (Figure 45).

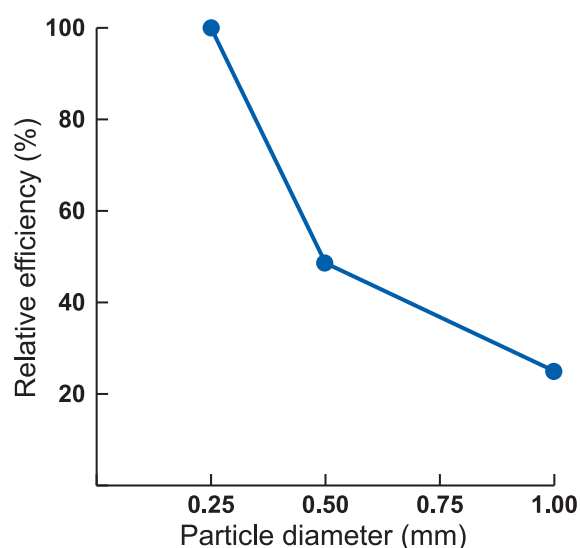


Figure 44 Relative efficiencies of particles of agricultural lime in changing soil pH for an application rate of 2.5 t/ha (from Cregan et al., 1989)



Figure 45 Coarse and fine limes with the same neutralising value treat the same amount of acidity; the fine lime does it quicker.