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Soil acidity... Is it a problem in Western Australia?

by W. M. Porter¹, W. J. Cox² and I. Wilson³

Increasing numbers of Western Australian farmers are taking an interest in soil acidity. Many blame it for declining pasture production, but extensive Department of Agriculture research has shown that this is no simple problem with simple answers.

Legume-based pastures provide good quality animal feed. They also improve soil fertility by building up soil nitrogen and organic matter, but in doing so they build up soil acidity which may be accentuated further by the use of nitrogen fertilisers in the cropping phase. This applies particularly to fertilisers containing sulphate of ammonia.

Most Western Australian soils are slightly acid in the natural state.

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What is soil acidity?
Soil acidity is most commonly described using the pH scale illustrated in Figure 1. The scale ranges from 1 to 14 with 7 defined as neutral, less than 7 as acid and more than 7 as alkaline. Most soils range between 4 and 8.5.

The pH of a soil is measured using a glass electrode attached to a meter, which is calibrated on a scale of 1 to 14. One part of soil is mixed with five parts of water and the pH of the suspension is reported as pH in 1:5 water. This is the method used most in Western Australia, for example by CSBP and Farmers and the Government Chemical Laboratories. Alternative techniques using weak calcium chloride or potassium chloride in place of water, result in readings about 0.5 to 1.0 units lower.

Although pH is a measure of soil acidity it does not provide information on the buffering capacity of the soil. Buffering capacity is the ability of a soil to resist a change in pH when mixed with an acid or alkaline (lime) source. This property determines how fast the soil pH changes when it is treated for acidity or alkalinity. Generally, grey sands have a low buffering capacity while loam and clay textured soils have a higher buffering capacity.

Factors affected by low pH
Soil pH affects a number of soil processes which in turn affect plant growth.

Low pH reduces the availability of phosphorus, calcium, magnesium and molybdenum (Figure 2). Thus deficiencies of these nutrients are more likely to occur in strongly acid than in weakly acid or neutral soils. In contrast, the availability of manganese and aluminium is increased at low pH. Therefore, where nutrient levels are adequate, the growth of sensitive plants could be reduced by toxic amounts of aluminium and/or manganese. The availability of these elements increases markedly below pH 5.5 (Figure 3). These elements affect nutrient uptake and availability in the plant and cause structural damage to the roots.
The availability of soil nitrogen also may be affected. Nitrification, the microbial process converting ammonium to nitrate, is reduced under acid conditions. The reverse applies if a soil is limed. Many of the responses to liming, particularly in pastures, are due to increased availability of soil nitrogen.

In the case of legumes such as subterranean clover, soil acidity affects not only nutrient availability but also the growth and survival of rhizobia, the nodulation initiation process and nitrogen fixation. Pasture establishment problems on acid soils often are associated with failure of rhizobia to survive.

The effects of soil acidity on plant growth

If a soil is extremely acid then the growth of plants on that soil is reduced. On severely acid soils clover plants tend to be stunted, with reddened leaf-stems. On some soils this poor growth occurs in the year of pasture establishment (Plate 1), and in subsequent years, results in capeweed dominance (Plate 2).

Wheat plants growing on very acid soils often have dead spots or patches in their leaves (Plate 3).

Unluckily, these symptoms are not specific nor are they defined well enough to be used to diagnose a soil acidity problem. The only way to determine if a soil is acid is to measure its pH, which is a simple procedure.

Plants adapted to a specific soil pH range have evolved in nature. Medics generally grow best on soils of a high (alkaline) pH, clovers do better on mildly acid soils and wheat grows satisfactorily in the pH range 5.0 to 8.0. Yields can be reduced outside this range. Of the cereals, oats is very tolerant, wheat is moderately tolerant and barley is least tolerant of soil acidity.

Within each plant species there is some variability in tolerance of acidity. For example many wheats from South America are extremely tolerant of aluminium toxicity. In contrast, all commercial Australian varieties have a low tolerance. The New South Wales Department of Agriculture has a large programme of research into selection of acid tolerant crop varieties and the incorporation of this tolerance into commercial varieties. This programme can be extended to Western Australia if soil acidity is found to have significant effects on the yield of existing varieties.

Location of acid soils

Western Australia has big areas of pale yellow and yellow sandplain soils which carried Wodgil (Acacia spp.) vegetation before clearing (Plate 4). Some Wodgil soils are naturally acid, having a pH of less than 5.5. An example of an acid Wodgil soil profile is shown in Plate 5. Such soils are common in the north-east and eastern

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Figure 1. The pH Scale

<table>
<thead>
<tr>
<th>Range of acidity</th>
<th>Degree</th>
<th>pH value</th>
</tr>
</thead>
<tbody>
<tr>
<td>strong</td>
<td>slight</td>
<td>neutral</td>
</tr>
<tr>
<td>medium</td>
<td>NEUTRAL</td>
<td>2</td>
</tr>
<tr>
<td>slight</td>
<td>moderate</td>
<td>3</td>
</tr>
<tr>
<td>strong</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Influence of pH on nutrient availability*

*The changes in width of the bands represent changes in the availability of the different plant nutrients to crops and pastures over a range of soil reactions. As the bands become narrower the nutrients are less available and as they become wider the availability increases. These lines show the general trends and are not a quantitative expression of pH versus nutrient availability.
wheatbelt, although there are smaller areas throughout the wheatbelt (Figure 4).

In 1979/80 the drought fertiliser service which was provided jointly by the Department of Agriculture and CSBP analysed over 9 000 soil samples from the declared drought zone and found that 5 per cent of these (representing 200 000 ha) had a pH less than 5.0. Another 24 per cent (representing 960 000 ha) had a pH between 5.0 and 5.5.

Wodgil soils also differ from most other soils in the region (for example mallee soils), in that the subsoil is more acid than the topsoil (Figure 5). Thus the subsoil of many Wodgil soils can be so acid as to reduce or inhibit root growth.

The other major area of acid soils is the 100 000 ha of peaty sands along the south coast and in isolated areas in the south-west (Figure 4). Liming has long been recognised as a necessity for pasture establishment on these soils (Fitzpatrick, 1958).

Certain other light-textured soils in the agricultural areas are naturally slightly acid, and may become progressively more acid with time (Figure 4). The rate of their acidity increase depends on the length of the pasture ley and the clover content of these pastures as well as on the extent of nitrogen fertiliser usage.

Factors influencing soil acidity
A number of natural and management factors can change soil pH. The large areas of acid soils probably result from leaching which has displaced calcium and magnesium from the exchange complex. The subterranean clover-superphosphate system and the use of nitrogen fertilisers may add to a potential problem.

The effect of pastures
Legume-based pastures, apart from providing valuable animal feed, also improve soil fertility by building up soil nitrogen and organic matter, but this also increases soil acidity. After roots and leaves die the nitrogen fixed by subclover and other legumes is converted by soil micro-organisms into nitrate nitrogen (the most common form of nitrogen used by plants). This process releases acid and increases acidity. Another component of the problem is the increase in organic matter following pasture establishment on virgin soils. This organic matter helps to increase the moisture retention properties of the soil. It also increases the retention of essential nutrients such as calcium and potassium. However this same soil organic matter contains a large number of carboxyl groups which dissociate to release hydrogen ions, resulting in a lower pH. Decreases in soil pH have been reported over a range of soil types in the Eastern States (Williams, 1980; Lee, 1980—Figure 6) and in Western Australia (Figure 7).

In New South Wales (Figures 6a and 6b) over 50 years the pH dropped by approximately one unit. This resulted in increased exchangeable manganese and aluminium. The pH decreased to a depth below 30 cm (Figure 6b).

In Western Australia a decrease in pH under improved pasture has been measured on a number of sandy soils at Coolup on the coastal plain (Barrow, 1969) at Kojonup (Watson, 1969) and at Newdegate (I. Rowland, unpublished data). The last example is typical of the wheatbelt in that it covered a number of cropping rotations.

The pH on all plots decreased from their original 6.1 (Figure 7). However, the pH of plots which had been continuously cropped only dropped to 5.75 while plots which had carried pasture became significantly more acid. Plots which had carried pasture for nine of the

Plate 1: Poor clover growth on acid Wodgil Soil (right). Note that lime application has improved the clover growth (left). This effect of lime occurred at Merredin Research Station. At 12 other sites lime had no effect on clover growth.
11 previous years dropped to pH 5.35. Thus, on average, for every year of pasture in the rotation, the soil pH dropped 0.04 units. No nitrogen was used with any of the crops.

The rate of soil pH decrease under improved pasture is likely to vary considerably from soil to soil. It will depend upon several interacting factors, including the initial pH, buffering capacity of the soil, the rate of organic matter build-up, the input of nitrogen by the legume and climatic conditions. In general the rate of acidification is likely to be greatest in light textured soils of low initial organic matter content.

The effect of superphosphate

Although superphosphate is itself somewhat acid, it does not seem to have a detectable effect on the acidity of the soil. The effect of superphosphate on soil acidity is indirect in that it increases the growth of clover and other pasture components. As a result of the increased nitrogen fixed, and increased soil organic matter there is a small increase in acidity. This is partially counteracted in high rainfall situations by the calcium in superphosphate. Any fertilisers such as trace elements and potassium that increase clover growth have a similar indirect effect on acidity.

Without these nutrients it would not be possible to grow productive pastures, so the long term trend towards increased acidity is a by-product of a very successful system of agriculture. It is possible to reverse this trend by lime application.

Some researchers have suggested that alternative sources of phosphorus, such as a rock phosphate or di-calcium phosphate, would minimise soil acidity effects (superphosphate mainly comprises water-soluble monocalcium phosphate). Unfortunately, the phosphorus in these sources is almost totally unavailable to plants, except on very acid soils such as the peaty sand along the south coast. In most soils, 30 to 110 times as much rock phosphate as superphosphate is needed to give the same pasture production. This is not economically viable.

Most nitrogen fertilisers used by wheatbelt farmers have the effect of slowly acidifying the soil and reducing soil pH. The acidifying effect of nitrogen fertilisers results from the conversion of the ammonium constituent of fertilisers to nitrate by soil micro-organisms. This reaction produces acid. The amount of acidity can be calculated from the composition of the fertiliser and the rate of application. The most convenient way to express the acidifying effects of a fertiliser is to show how much pure lime would be needed to neutralise the acid it produced. Sulphate of ammonia and mono- and di-ammonium phosphates are twice as acidifying as urea and ammonium nitrate per unit of applied nitrogen (Table 1). On a 'per kilogram' basis the most acidifying fertiliser is urea (because of its high percentage of nitrogen) followed by sulphate of ammonia, D.A.P., ammonium nitrate and M.A.P.
Table 1. Lime requirement to neutralise potential acidity in a range of nitrogen fertilisers

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>%N</th>
<th>Kg Lime+ 100 kgN</th>
<th>Kg Lime/100 Kg fertiliser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphate of Ammonia......</td>
<td>21</td>
<td>715</td>
<td>150</td>
</tr>
<tr>
<td>M.A.P</td>
<td>12</td>
<td>715</td>
<td>86</td>
</tr>
<tr>
<td>D.A.P</td>
<td>18</td>
<td>715</td>
<td>129</td>
</tr>
<tr>
<td>Urea</td>
<td>46</td>
<td>357</td>
<td>164</td>
</tr>
<tr>
<td>Ammonium nitrate.........</td>
<td>34</td>
<td>357</td>
<td>121</td>
</tr>
</tbody>
</table>

* Pure lime

Table 2. Effect of Continuous Cropping with Three Nitrogen Sources on Soil pH at Three Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>Nil N</th>
<th>Calcium ammonium nitrate</th>
<th>Sulphate of ammonia</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wongan Hills</td>
<td>Yellow, loamy sand</td>
<td>5.8</td>
<td>5.6</td>
<td>4.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Merredin</td>
<td>Yellow, loamy sand</td>
<td>5.4</td>
<td>5.4</td>
<td>4.5</td>
<td>5.2</td>
</tr>
<tr>
<td>Beverley</td>
<td>Red brown loam</td>
<td>6.3</td>
<td>5.7</td>
<td>5.2</td>
<td>5.8</td>
</tr>
</tbody>
</table>

This is the maximum amount of acidity these fertilisers can produce. Many plant and soil factors, including plant uptake and leaching of nitrogen, reduce the amount of acidity produced so the amounts of lime indicated in Table 1 are higher than those required in practice. However they provide a valid comparison between nitrogen sources.

The rate of soil acidification as a result of nitrogen fertiliser application is illustrated by data from a continuous cropping trial (Mason, 1980) in Table 2. Sulphate of ammonia caused the greatest reduction when nitrogen was applied at 76 kg N/ha/year for 12 years. It caused the most noticeable drop in pH on all soil types. The final pH was approximately one unit lower. Under commercial conditions the rate of pH decrease would be smaller, because lower rates of nitrogen would be used. Calcium ammonium nitrate had only a small effect and then only at two of the sites.

The decrease in pH (increase in soil acidity) resulting from the pasture ley system and/or the use of
nitrogen fertilisers is only significant if it drops below the critical level at which plant growth is affected, for example as a result of aluminium toxicity (see Fig. 2 for aluminium availability at different pHs).

The rate of soil acidity increase depends not only on the initial soil pH, the number of years of pasture, the number of crops and the amount of nitrogen fertiliser for each crop, but on the soil type as well. Soils with high buffering capacity and an initial pH between 6 and 7 will take many generations of farming to be reduced to pH 5, or less, at which plant growth is likely to be affected. In contrast the naturally-acid soils with a low buffering capacity acidify rapidly.

**Results from recent research**

Research into soil acidity problems in Western Australia is not a new development. Work in the early 1950's highlighted the need for lime application on acid peaty sands along the south coast. It resulted also in the lime pelleting technique for subclover establishment on all soils.

Following the identification of acid soils in the agricultural areas of the south-west a new programme was started in 1980 to:

- Identify the components of the soil acidity problem.
- Develop methods to overcome soil acidity problems.
- Predict acidification rates associated with the use of nitrogen fertilisers on the major Western Australian soil types.

Lime application to acid topsoil or subsoil in glasshouse trials brought big increases in wheat vegetative yield (Table 3). Subsoils were the more responsive. Molybdenum gave smaller responses (Plate 6).

Plant growth increased as the pH increased up to a pH of 5.0 (Figure 8). Above this pH there was no effect from liming. Chemical analysis of soils and plants indicated that the yield depressions resulted from a combination of aluminium toxicity and

*Table 3. Vegetative wheat yields (g/pot)*

<table>
<thead>
<tr>
<th>Source of Soil</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>Complete nutrients*</th>
<th>No Lime</th>
<th>No molybdenum</th>
<th>No lime-No Molybdenum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gutha ..........</td>
<td>0-10</td>
<td>4.6</td>
<td>5.9</td>
<td>4.4</td>
<td>5.1</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>10-30</td>
<td>4.3</td>
<td>5.7</td>
<td>2.1</td>
<td>5.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Kalannie ......</td>
<td>0-10</td>
<td>4.7</td>
<td>10.8</td>
<td>10.3</td>
<td>11.0</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td>10-30</td>
<td>4.4</td>
<td>12.0</td>
<td>0.5</td>
<td>11.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Yelbeni .......</td>
<td>0-10</td>
<td>4.7</td>
<td>5.8</td>
<td>5.2</td>
<td>5.8</td>
<td>4.5</td>
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<td>2.7</td>
<td>5.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>

*Includes lime

The effect of pasture age on soil pH (Figure 6a) and soil profile pH (Figure 6b) (after Williams, 1980)

Plate 4: Wodgil (Acacia sp.) vegetation growing on acid soil.
molybdenum deficiency. Manganese toxicity was not a problem on the soils tested.

These results provided the basis for a series of 14 field trials investigating the lime and molybdenum requirement of wheat and clover. The majority of trials were badly affected by drought but a number showed growth responses to lime and/or molybdenum early in the season. At harvest most of these differences had disappeared. However a number of trials, for instance one at East Perenjori (Table 4) gave responses ranging from 100 to 200 kg/ha of wheat grain. This parallels other results obtained by CSBP on comparable soil types (Anon., 1980).

The majority of trials showed no effect of treatment on clover growth probably because the seed was inoculated and lime pelleted. Since soil acidity affects the survival of rhizobium bacteria then differences would be expected in the second and subsequent years. In one trial at Merredin Research Station on a known problem soil the clover failed to establish without lime (Plate 1) even though the seed had been lime pelleted and inoculated.

**How to correct soil acidity**

There are two main ways to contend with soil acidity if the pH is low enough to affect pasture and crop production. One way is to grow crops and pasture species that are tolerant of soil acidity. The other way is to lime the soil.

**Liming cannot be recommended at present except for pasture establishment on acid peaty sands. Further research is required to define the need for lime and the economics of lime application. Indiscriminate lime application can lead to severe problems.**

Farmers who suspect they have acid soils should discuss the problem with agricultural advisers and consultants. Simple lime strips at 1 tonne/ha are suggested as a prerequisite to whole-paddock liming.

Where lime is required the quantity to be applied depends on:
- type of lime
- neutralising value

The amount of lime needed increases as the soil acidity increases. Also more lime is needed for soils of high organic matter content than for soils low in organic matter. Clayey soils also need more lime than sandy soils of the same pH. Lime can be applied at any time during the year. To obtain the most benefit from lime it should be thoroughly mixed with the soil to plough depth. A summer-autumn topdressing followed by cultivation will mix the lime with the soil. The lime will not react with the soil until the soil becomes wet. Lime must be applied at much higher rates than fertiliser. Most fertiliser spreaders do not apply a high enough rate. Modifications to equipment may increase the rate of application.

Liming probably has a very slow effect on subsoil acidity. If subsoil acidity is a problem, it may be best to grow crop and pasture varieties which are more acid tolerant.

**How does lime affect soils?**

Liming an acid soil not only increases pH but also affects nutrient availability. The most significant influence on problem...
soils is that it reduces the availability of aluminium and manganese. The availability of potassium and magnesium is reduced also. As many Western Australian soils are marginal in both manganese and potassium, care is required to ensure that only enough lime is applied to cure the problem without inducing other deficiencies.

The availability of molybdenum is increased by an increase in pH resulting from liming. This increase can be dramatic, so in no case should lime and molybdenum be applied together. Although our preliminary results implicate molybdenum deficiency as a component of the soil acidity problem, further additions of molybdenum may be dangerous. Liming in such a situation may increase the availability of molybdenum so much as to cause excessively high levels in pastures. This can induce copper deficiency in animals.

The high calcium content of limestone makes this nutrient more available, as does superphosphate. Over-liming can reduce phosphate availability. Large, temporary increases in the release of nitrogen also have been noted as a result of liming.

Plate 5: Profile of deep Wodgil sand. Gravel often occurs in the profile, sometimes forming a large proportion of the soil.

Research
Departmental researchers have launched a comprehensive programme to investigate a number of facets of soil acidity. It emphasises studies of the lime and/or molybdenum requirement of affected soils. A soil test for predicting the lime requirement of crops and pastures is being examined in these trials. Other trials centre on the residual value of lime and methods of lime application. A concurrent programme aims at predicting the rate of acidification on soils throughout the wheatbelt.

The strongest emphasis is on trials in the wheatbelt but a number of lime trials are being conducted to investigate soil acidity in the high rainfall areas. Staff at the Albany and Bunbury Regional Centres are handling this section.

Information from this research programme is essential for the development of appropriate policies and farming strategies to minimise or reverse changes in soil pH.

Conclusions
There is strong evidence that production on large areas of naturally acid soils is affected as a result of combined aluminium toxicity and/or molybdenum deficiency.

It is likely that soil acidity will increase on most light land soils in Western Australia as a result of the clover ley effects and the use of nitrogen fertilisers. The extent of the soil acidity problem and estimates of its rate of increase in the future are being studied.

Research will emphasise the development of economic methods to prevent or cure soil acidity increase, including methods of lime application and the best liming materials to use.

Acknowledgements
This research is funded by the Commonwealth Wheat Industry Research Council. Their generous support is gratefully acknowledged. The authors also wish to thank their colleagues in the Department of Agriculture and the Government Chemical Laboratories for their willing co-operation in the field programme and laboratory analysis.

Plate 6: Lime and molybdenum response in wheat.

References