Soil acidity: a guide for WA farmers and consultants.

Chris Gazey
Stephen Davies
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Soil acidity

A guide for WA farmers and consultants

Second edition

Bulletin 4858, April 2014

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Preface

Our first edition of *Soil acidity: a guide for WA farmers and consultants* in 2009 was a significant publication which brought together current knowledge on the management of soil acidity in WA in a user-friendly book. Three thousand printed copies were distributed and an interactive PDF on the Department of Agriculture and Food, Western Australia (DAFWA) website made it available to most WA farmers and consultants.

Recent projects have extended our knowledge of the extent of the soil acidity problem in WA. When the first edition was published, we had good information about soil acidity in the Avon River Basin. Follow-up projects confirmed that low soil pH, particularly in the subsurface below 10 cm, is a major concern for all south-west WA agriculture and requires immediate attention. Contemporary maps of the soil condition are shown in the ‘Overview of soil acidity in WA’. Each of the 361 farmers participating in the project soil sampling were provided with individual liming plans and gained a better understanding of the soil pH profile on their farm. Delivery of this information at workshops held for the participating grower groups has enabled regions to gain a better understanding of the current situation and how to prioritise their soil constraints. More than 1800 growers participated in the workshops and talks at regional field days and, in addition to increasing their knowledge, they provided information on current practices and barriers to the adoption of liming to manage soil acidity in WA. This information, in conjunction with feedback on the first edition of the guide, indicated the need for an updated second edition.

For the second edition, we have Ronald Master, from the DAFWA Albany office, on the authorship team to provide a perspective from the south of the agricultural region. The second edition has a modern layout but retains the user-friendly concepts of the first. The guide is rich in examples, diagrams and photographs.
Readers can choose to gain an overview by reading the focus text and figure captions and read in detail sections of interest. I am sure that, as with the first edition, many will choose to read from cover to cover. A background in science is not required to understand the ‘Chemistry and biology of soil acidity’ chapter and the comprehensive glossary explains the technical terms. Other readers will be interested in the practicalities of the ‘Managing soil acidity’ and ‘Agricultural lime guide’ chapters.

This edition also has a new ‘Case studies in soil acidity management’ chapter, which demonstrates the long-term benefits of liming and the latest techniques being used to combat severe soil acidity. We have updated and answered the latest ‘Frequently asked soil acidity questions’ from workshops, field days and enquires to the department to make this guide current and relevant to WA farmers and consultants.

I sincerely hope that this guide assists the farmers of WA to make the best choices in soil acidity management on their farm.

Chris Gazey

Chris Gazey

Stephen Davies

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Overview of soil acidity in WA

Soil acidity is an economic and natural resource threat throughout the south-western agricultural area of Western Australia (Figure 1). Production loss and sustainability are of major concern to farmers, with more than 14.25 million hectares of wheatbelt soils currently estimated to be acidic or at risk of becoming acidic to the point of restricting production. The estimate of production loss for the wheatbelt due to acidity is $498 million (Herbert 2009), or about 9% of the annual crop.

Approximately 161,000 soil samples, including about 67,000 from the subsurface, collected from over 93,000 sites across the south-west agricultural area from 2005–2012 were used to assess the current soil acidity situation (Gaze et al. 2013). These samples show that 72% of topsoils and 45% of subsurface soils were below the targets of $\text{pH}_{\text{ca}}$ 5.5 and 4.8, respectively. Mapping of this information at the farm scale showed that the extent and severity of acidity varies geographically and with soil type (Figures 2 and 3).

Figure 1. The south-west of WA showing the agricultural area divided into Agricultural Soil Zones (Ag Soil Zones) and locations of the towns referred to in this publication.
Overview of soil acidity in WA (continued)

The Central Northern Wheatbelt Ag Soil Zone soil samples, which are dominated by sandy earths, had 72% of topsoil samples and 66% of subsurface samples below the pH targets. In contrast, gravel soils of the Darling Range and South Coast Ag Soil Zones returned 89% of topsoil samples below the target, however, subsurface acidity was less common with 34% of subsurface samples below target. A similar pattern for the deep sandy duplex soils of the Southern Wheatbelt Ag Soil Zone was observed with 84% of topsoil samples below target and 36% of subsurface samples below the targets (Gazey et al. 2013).

A comparison of samples collected from 2004–06 to the 2010–12 samples showed that for most of the south-west, the situation has remained static. In some areas, particularly around the West Midlands and Central Northern Wheatbelt Ag Soil Zones, the situation has improved, but 50–75% of samples were still below target (Gazey et al. 2013).

Figure 2 Percentage of sites sampled (2005–12) with soil pH at 0–10cm depth below the DAFWA target of pHca 5.5 (Gazey et al. 2013). Numbers 1–11 indicate Ag Soil Zones (Figure 1).

0–10cm samples
% below target
75–100
50–74
20–49
10–19
0–9
Native vegetation
Figure 3 Percentage of sites sampled (2005–12) with soil pH at 10–20cm depth (left) and 20–30cm (right) below the DAFWA target of pH$_{ca}$ 4.8 (Gazey et al. 2013). Numbers 1–11 indicate Ag Soil Zones (Figure 1).
Overview of soil acidity in WA (continued)

Soil acidity is one of the few soil constraints, particularly subsurface constraints, that can be treated with appropriate management. There is increasing recognition amongst growers that lime use needs to increase. Of over 334 farmers and advisors from across the wheatbelt surveyed over 2010–13, 74% considered soil acidity to be a moderate or greater problem on their farm (Figure 4).

The farmers indicated that the most common rates of application of lime would increase from 1–1.5 tonnes per hectare (t/ha) to 1.5–2t/ha (Figure 5). Most of these farms would need to apply at least 2t/ha every 3–4 years over a 10-year period to achieve appropriate soil pH and after that, maintenance liming of 1–2 t/ha every 4–7 years would be required to maintain soil pH.

The rate of soil acidification is increased under productive agriculture, however liming rates have not

Figure 4 How surveyed farmers and advisors (responses = 334) rated soil acidity as a problem on their farms.

increased in line with increased production. In the period 1983–93, the average wheat yield was 1.36t/ha. With improved farming practice and

Figure 5 Rates of lime farmers had applied in the past (responses = 410) and intended rates of application in the future (responses = 115).
varieties, average yield over 1993–2013 was 1.65t/ha. Liming over the last 20 years has been insufficient to counter acidification. In addition new crop and pasture varieties have allowed production on already acidic soil. Without sufficient lime the soil has continued to acidify.

The trend in lime use is positive (Figure 6). However the current amount of lime used is only half of the estimated requirement of 2.5 million tonnes per year for the next 10 years to achieve appropriate soil pH in most soils across the south-west agricultural area.

Degradation of the soil resource has implications wider than the immediate concerns of production and profitability. Sustainability should also consider offsite impacts of soil acidity such as degradation of waterways (from increased water run-off containing eroded soil and nutrients), groundwater pollution (from increased leaching of nutrients) and dryland salinity (from reduced water usage).

Figure 6 Agricultural lime sales 2004–13 in the south-west of WA. Source: lime sales figures from Lime WA Inc. and other contributing suppliers of agricultural lime (estimated total market share 85–95%).
Part 1

Managing soil acidity

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Diagnosing soil acidity

The only way to diagnose soil acidity is to sample the soil and test the pH. While liming to counter soil acidity needs to be part of normal farming practice in most of the wheatbelt, accurate knowledge of the soil pH allows more precise management decisions.

Soil sampling
Topsoil pH can be quite different from the subsurface soil pH (Figure 7) and sampling only the topsoil may lead to inadequate lime applications. Acidity in the subsurface cannot be detected or estimated by knowing the topsoil pH. Samples should be taken at 0–10,
10–20 and 20–30 centimetres (cm) to determine a soil pH profile.

Ideally, soil samples should be taken in summer when most soils are hot and dry with minimal biological activity. This will minimise the impact of seasonal variations in pH, which will be further reduced by measuring pH in a calcium chloride solution rather than water.

Paddock variability, particularly soil type changes, should be taken into account when designing sampling programs. It is important not to undersample; knowing and understanding ‘management areas’ within paddocks will allow targeted lime inputs to maximise economic return. For example, clay soils are generally slower to acidify but require more lime to lift pH when they become acidic.

**Commercial contractors**

The best option is to use a specialised soil-sampling contractor and seek expert advice for individual liming recommendations (Figure 8).

![Figure 8 Soil sampling at Kellerberrin. Professional soil-sampling contractors should be able to accurately sample the soil profile.](image)

Professional soil-sampling contractors should geo-locate sampling sites and arrange laboratory testing of the samples. They may also provide record-keeping services and liming recommendations. Sampling for soil pH testing is often done in conjunction with soil nutrient sampling for fertiliser recommendations.
Diagnosing soil acidity (continued)

Do-it-yourself sampling
A do-it-yourself approach to soil sampling is possible. Divide the paddock up according to soil type and areas that have different crop or pasture growth. Typically, six to eight sample sites per paddock is adequate, with representative sites from each soil type or management area in the paddock. If the paddock is uniform, a grid pattern can be used or evenly space sites over the whole paddock. Avoid unrepresentative areas such as stock camps, paddock corners and harvest windrows.

Collect cores from around each site and bulk them into one sample, keeping the 0–10, 10–20 and 20–30cm layers separate and being careful to prevent topsoil contamination of the subsurface samples.

Traditionally, soil sampling has been done with a ‘pogo stick’ sampler, designed to sample the top 10cm of soil. This type of sampler is unsuitable to sample the 10–20 and 20–30cm soil layers that are necessary for soil pH sampling. A 5cm diameter exhaust tube, marked in 10cm increments, is a suitable alternative (Figure 9).

Soil samples should be sent to a laboratory accredited with the Australasian Soil and Plant Analysis Council Inc. and the pH measured in a one part soil to five parts 0.01 molar (M) calcium chloride solution (see ‘Measurement of pH’, page 40). In this guide, all recommendations are based on pH measured in calcium chloride and designated pHCa. pHCa is on average 0.7 of a unit lower than other methods.

Do-it-yourself soil sampling has a number of drawbacks; it requires a dedication to the task and inputs of time for sampling, arranging laboratory testing, sourcing liming recommendations and accurate record keeping to enable comparable repeat sampling over years for monitoring pH change.

Figure 9 An exhaust tube marked in 10cm increments is useful for do-it-yourself sampling.
Commercial soil sampling kits
Prepaid commercial soil sampling kits are available and may be the most convenient method for the do-it-yourself approach as they include full instructions, sample bags, postage and laboratory testing of the samples. These kits are primarily aimed at topsoil sampling and testing for fertiliser recommendations, but the subsurface 10–20 and 20–30cm layers may be sampled for pH at the same time (a suitable sampling tube, or commercial soil sampling contractor able to accurately sample the subsurface, will need to be used).

Field pH testing
Laboratory testing of pH provides the most accurate measurement of soil pH. Field testing with a hand-held pH probe may provide an indication of areas that need accurate soil sampling and testing. Hand-held pH probes are available from scientific equipment suppliers and come with instructions. When field testing soil pH, it is usually more convenient to use deionised or distilled water (1 part soil to 5 parts water) instead of 0.01M calcium chloride and so the results will need to be converted by subtracting 0.7. It is important to maintain the probe in good condition and calibrate with standard pH buffer solutions each day it is used.

Soil pH test kits that use indicator solutions and colour estimate a water pH (0.7 should be subtracted). They are inexpensive and easy to use, however, the results are subjective and should be used with caution. The chemicals used with the kits are subject to deterioration.

Electro-magnetic (EM) mapping
Electro-magnetic mapping shows soil type variability across the farm. While soil type does influence the pH of the soil and the acidification rate, EM mapping cannot take into account the farming and liming history of the soil. The pH will differ according to how long the soil has been farmed, what type of farming has been conducted and how much and how often lime has been applied. Consequently, the relationship between EM results and current soil pH is variable.

Monitoring soil pH
Monitoring changes in soil pH is an important part of soil acidity management. Re-sampling every three to four years will enable you to refine your liming program to prevent good soil from becoming acidic and avoid liming unnecessarily on soil that doesn’t need it.

Because pH can vary within a paddock, tracking changes in the soil pH requires samples to be collected from the same location over time. Samples need to be properly geo-located, preferably by global positioning system (GPS), to allow comparable repeat sampling.

Sampling 25% of a farm each year enables a four-year rotation. This is an adequate time frame to detect changes and allow adjustment of liming practices.
Developing a liming program

Soil acidification is an inevitable and ongoing consequence of productive agriculture. When ongoing soil acidification is managed as part of the farming system soil can be prevented from becoming acidic.

**Appropriate pH**

DAFWA recommends soil pH$_{C_8}$ values at or above 5.5 in the topsoil and 4.8 in the subsurface. These values have been developed based on hundreds of trial-years of data. Maintaining topsoil pH$_{C_8}$ above 5.5 will treat ongoing acidification and ensure that sufficient alkalinity can move down the soil profile and treat subsurface acidification. The
effects of aluminium toxicity in the subsurface are minimised if the pH$_{ca}$ is above 4.8.

Soil pH test results can be interpreted using DAFWA targets as a basis. If the top and subsurface soil pH values are at or above target values, only maintenance levels of agricultural lime (predominantly calcium carbonate (CaCO$_3$)) will be required to counter ongoing acidification due to agriculture. If the topsoil pH$_{ca}$ is below 5.5, recovery liming is recommended to prevent the development of subsurface acidity, even if the subsurface pH$_{ca}$ is currently at 4.8. When the topsoil pH$_{ca}$ is below 5.5, insufficient alkalinity can move down to counter ongoing acidification in the subsurface and the pH is likely to drop. If the subsurface pH$_{ca}$ is below 4.8, liming to maintain (or recover) topsoil pH$_{ca}$ at or above 5.5 is essential and subsurface pH should be monitored in three to four years so that the liming rates can be adjusted if insufficient alkalinity has moved down to treat the subsurface acidity.

**Maintenance liming**

Knowing how farming system inputs and exports contribute to soil acidification will help to calculate the amount of lime required to counter ongoing soil acidification due to agriculture (maintenance liming). Different amounts of alkalinity are exported in various farm products and need to be replaced in the form of lime to prevent soils acidifying (Table 1).

The amounts of lime required to counter the acidifying effects of common nitrogen fertilisers are given in Table 2. Ammonium fertilisers are the most acidifying. Elemental sulfur can contribute to soil acidification when it is converted to sulfate (the form that can be taken up by plants), however, relatively little elemental sulfur is applied in WA farming systems and its contribution is small compared to ammonium fertilisers. If sulfur is applied in the form of sulfate, as in calcium sulfate (gypsum) it is non-acidifying. Phosphate fertilisers are non-acidifying.

**Table 1 The lime equivalent (as kilograms per tonne (kg/t) of pure calcium carbonate) of various farm products (Moore 1998).**

<table>
<thead>
<tr>
<th>Product removed</th>
<th>CaCO$_3$ equivalent (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal grains: wheat</td>
<td>9</td>
</tr>
<tr>
<td>barley</td>
<td>8</td>
</tr>
<tr>
<td>triticale</td>
<td>7</td>
</tr>
<tr>
<td>Cereal whole tops</td>
<td>20</td>
</tr>
<tr>
<td>Canola</td>
<td>2</td>
</tr>
<tr>
<td>Lupin: grain</td>
<td>20</td>
</tr>
<tr>
<td>whole tops</td>
<td>60</td>
</tr>
<tr>
<td>Lucerne hay</td>
<td>60</td>
</tr>
<tr>
<td>Hay (mixed grasses)</td>
<td>30</td>
</tr>
<tr>
<td>Subclover (whole plant)</td>
<td>40</td>
</tr>
<tr>
<td>Sheep: dung</td>
<td>25</td>
</tr>
<tr>
<td>urine</td>
<td>9</td>
</tr>
<tr>
<td>lambs</td>
<td>3</td>
</tr>
<tr>
<td>wool (6kg/sheep)</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Developing a liming program (continued)

Table 2 Lime (as kilograms (kg) of pure calcium carbonate) required to neutralise acidity generated by common nitrogen fertilisers (Moore 1998).

<table>
<thead>
<tr>
<th>Nitrogen fertiliser</th>
<th>CaCO₃ required to neutralise nitrogen addition (kg CaCO₃ per kg nitrogen)¹</th>
<th>none leached</th>
<th>100% leached</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium sulfate</td>
<td>3.6</td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td>Monoammonium phosphate (MAP)</td>
<td>3.6</td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>0</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td>0</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Diammonium phosphate (DAP)</td>
<td>1.8</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>-3.6²</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

¹Per weight of nitrogen (N) in the fertiliser, not per weight of the fertiliser.
²Negative values indicate a liming effect by the fertiliser.

Typically, a wheatbelt farming system operating a winter crop/pasture rotation in WA has an acidification rate equivalent to 25–345 kilograms per hectare per year (kg/ha/year) of pure calcium carbonate (National Land and Water Resources Audit 2001). Required liming rates can only be estimated and monitoring of the soil pH profile every three to four years is recommended so the liming program can be refined.

Recovery liming

Estimating the amount of lime required to recover acidic soil to recommended pH targets is complicated. Enough lime needs to be applied to treat ongoing acidification as well as the already acidified soil (Figure 10).

The rule-of-thumb guide (Table 3) indicates the amount of lime that may need to be applied to sandy soils over 5 years to achieve $pH_{Ca}$ above 5.5 in

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>$pH_{Ca}$</th>
<th>Lime amount over 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>&lt; 5</td>
<td>2 t/ha</td>
</tr>
<tr>
<td></td>
<td>&lt; 5.5</td>
<td>1 t/ha</td>
</tr>
<tr>
<td>10–20</td>
<td>&lt; 4.5</td>
<td>2 t/ha</td>
</tr>
<tr>
<td></td>
<td>&lt; 4.8</td>
<td>1 t/ha</td>
</tr>
<tr>
<td>20–30</td>
<td>&lt; 4.5</td>
<td>1 t/ha</td>
</tr>
<tr>
<td></td>
<td>&lt; 4.8</td>
<td>measure pH in 3 years</td>
</tr>
</tbody>
</table>
Applying agricultural lime is the most cost-effective way of treating soil acidity. The amount of lime required will depend on the current pH profile, soil type, rainfall, farming system and lime quality.

the topsoil and 4.8 in the subsurface after 10 years. Where more information is known about the farm and farming system, a 10-year liming plan can be developed. Increases in pH will depend on soil type, rainfall, lime quality and quantity applied and other farming practices as well as the soil pH profile. Expert advice should be sought for individual recommendations.

Monitoring the topsoil and subsurface soil about every three years is very

Figure 10 Liming trial at South Bodallin. When enough lime is applied to treat an acidic soil profile significant plant growth and production responses can be achieved.
Developing a liming program (continued)

important when liming to recover acidic subsurface soil. This will allow adjustment of the liming schedule as the soil pH increases or if it does not respond as expected. It is essential to maintain the topsoil pH$_{Ca}$ above 5.5 for alkalinity to move down to treat acidity in the subsurface soil.

**Liming effectively**

The best use of lime is achieved when you know how much to apply and where to apply it. Monitoring soil pH in the topsoil and subsurface identifies priority areas, which allows liming to be targeted to achieve the best economic return. More lime can be applied where necessary, rather than a lower rate over whole paddocks.

The old recommendation of 1 tonne per hectare (t/ha) of lime every 10 years applied over the whole paddock is usually not the most effective way of applying lime; some areas will receive too much lime and others too little. Overall production has increased on most farms due to improved farming practice and so acidification of the soil has also increased. Current liming recommendations, to achieve appropriate pH, are often greater than 2t/ha but need to be based on soil pH test results so that the lime can be targeted to management areas within paddocks as required.

Where it is not practical to lime all paddocks that need it, you need to prioritise but always apply the recommended rate of lime that will treat acidity in the surface and subsurface. If your best performing paddocks are at risk of acidifying, give them the highest priority. Next, identify the soils that are likely to give the greatest benefit from liming. For example, soils where an acidic layer restricts root growth into good soil below. These may not be the most acidic soils.

Guessing how much lime to apply from only topsoil samples can lead to inadequate lime application. Applying too little lime does not treat subsurface acidity; yield will continue to be lost as subsurface pH continues to decline and inhibit root growth.

Figure 11 demonstrates the hazards of only testing the topsoil. Testing the topsoil could show that the topsoil is acidic but reveals nothing about the subsurface. The universal pH indicator stain shows that this soil profile is acidic to about 40cm with good soil below. Sufficient lime to treat the topsoil based on only topsoil testing would be insufficient to treat the acidic layer down to 40cm and the barrier to root growth would still exist. Testing the 10–20 and 20–30cm layers would allow liming rates to be determined to treat the acidic layer and allow root access to the good soil below. Soils with this
kind of pH profile are likely to show large responses to liming.

Testing topsoil pH only tells you about topsoil pH.

Extra lime is required to treat the acidic subsurface layer from about 10 to 40cm. If you know your subsurface soil pH, you can apply the right amount of lime to treat it if necessary.

The acidic layer prevents roots from growing into the good soil below 40cm.

Figure 11 Soil profile stained with universal pH indicator at Tammin shows an acidic subsurface layer (stained orange), which would not be detected by only sampling topsoil, and soil with good pH (stained green) beneath.
Developing a liming program (continued)

A worked example

The following example shows the benefits of monitoring the soil pH at 0–10, 10–20 and 20–30cm. There is a great danger of underliming if only topsoil pH is taken into account, by almost 60% overall in this example, and at the same time unnecessarily liming in some areas.

This example is worked from actual pH data from the paddock shown in Figure 12. Where only the topsoil pH values are considered, the recommended lime application rate can only be given as a range because the pH of the subsurface soil may be anywhere from ideal to extremely acidic. The recommendation can be refined where the soil pH profile is known (Table 4).

Three commonly used liming options were considered (Table 5):

Option 1: No soil pH values are taken into account. Lime is applied at 1t/ha over the whole paddock.

Using this option, no area would receive the right amount of lime. Not enough would be applied at sites 1, 2, 4 and 5 and too much would be applied to sites 3 and 6.

Option 2: Only the topsoil pH values are taken into account. Lime is applied to targeted areas at the lowest rate recommended.

The total amount of lime applied would be similar to option 1. The correct amount of lime would be applied at three sites, but at sites 2, 4 and 6 too little would be applied and the subsurface soil would continue to acidify.

Option 3: pH values from 0–10, 10–20 and 20–30cm are taken into account. Lime is applied to targeted areas at the recommended rates.

The total amount of lime applied would be 1.8 times option 1. The method used would be to immediately spread 2t/ha on all areas that require liming. Then in two to four years time 1 or 2t/ha would be spread on the areas that required 3 or 4t/ha over the 10-year period. Resampling the soil in three to four years would allow adjustment of liming rates as necessary.
Table 4 Soil pH at six sites in one paddock (Figure 12) and the recommended liming rates when pH of topsoil only or pH of all three depths is taken into account.

| Site | Soil type   | Soil pH | Recommended lime over 10 years (t/ha) |  
|------|-------------|---------|--------------------------------------|---|
|      |             | 0–10cm  | 10–20cm | 20–30cm | based on pH from 0–10cm only | based on pH from 0–10, 10–20 & 20–30cm |
| 1    | sandy loam  | 5.0     | 4.6     | 4.8     | 2-4 | 2 |
| 2    | loam        | 5.3     | 4.3     | 4.6     | 2-4 | 3 |
| 3    | loamy clay  | 6.9     | 7.7     | 8.0     | 0-3 | 0 |
| 4    | sandy loam  | 5.6     | 4.5     | 4.5     | 1-3 | 2 |
| 5    | sandy loam  | 4.9     | 4.1     | 4.1     | 2-4 | 4 |
| 6    | loamy clay  | 6.7     | 7.2     | 7.9     | 0-3 | 0 |

Table 5 Lime required for three liming options:
1. blanket 1t/ha lime
2. lowest rate recommended based on topsoil pH only (Table 4)
3. recommended rate based on soil profile pH (Table 4).

| Site | Area (ha) | Lime required over 10 years (t) |  
|------|-----------|----------------------------------|---|
|      |           | Option 1 | Option 2 | Option 3 |
| 1    | 10        | 10       | 20       | 20       |
| 2    | 10        | 10       | 20       | 30       |
| 3    | 15        | 15       | 0        | 0        |
| 4    | 23        | 23       | 23       | 46       |
| 5    | 16        | 16       | 32       | 64       |
| 6    | 16        | 16       | 0        | 0        |
| Total| 90ha      | 90t      | 95t      | 160t     |
Applying lime

If you are deep-ripping, ploughing or spading to remove subsurface compaction or another constraint, it is a good idea to incorporate lime in the same operation.

Liming techniques

Whether liming to maintain or recover soil pH, surface application (at appropriate rates) is currently the recommended method for most situations (Figure 13). In time, sufficient surface application of lime will treat subsurface acidity.

Recently, incorporation of lime into the soil by mouldboard ploughing or rotary spading has shown promising results and can, if done appropriately, rapidly recover acidic subsurface soil to an appropriate pH (see the Tony

Figure 13 Surface application of lime south of Northam. Sufficient surface-applied lime can prevent the subsurface becoming acidic.
White, Miling case study, page 76). Rotary spading generally achieves a better distribution of lime through the soil profile than mouldboard ploughing, which buries the lime with the topsoil, leaving an acidic layer on the surface.

If you are ploughing or spading to remove another constraint, then it is worth considering the opportunity to incorporate lime to treat subsurface acidity. The risks, costs and returns need to be carefully evaluated before undertaking an expensive process such as ploughing or spading just to incorporate lime for quick recovery of acidic subsurface soil.

Good results have been achieved with deep placement of lime by direct injection using modified farm-scale machinery (Figure 14), but it is difficult and time-consuming to achieve the desired distribution, and ineffective and expensive if it is not achieved. Deep placement is only recommended for soils in which subsurface acidity is constraining production and, before it is attempted, detailed consideration should be given to whether it is likely to be profitable.

**Surface application**

The main aim when applying lime to the surface should be an even coverage of the ground. The spreading width should be approximately 6–8 metres (m) (depending on wind conditions) to get good coverage of fine particles less than 0.5 millimetres (mm). Spreading too wide results in uneven treatment of soil acidity. Larger particles will spread up to 15m but the effective distribution is poor and will result in variable change in pH.

**Surface applied then deep-rip**

It is good practice when applying lime to spread the lime prior to any soil disturbance such as deep-ripping, ploughing or spading. This enables better distribution of the lime particles and greater contact with the acidic soil. Liming before deep-ripping
Applying lime (continued)

for compaction adds value to both treatments.

**Direct injection**
This technique deep-places lime during deep-ripping, using modified machinery (Figure 14). Research has shown that successful direct injection is possible (Figure 15, right) and subsurface acidity can be quickly removed as a production constraint. When the distribution of lime is correct, yield responses of 20–30% in wheat are common. However, increased costs due to machinery modification and slow operation need to be considered. It is difficult to achieve adequate distribution of the lime. Poor distribution can result in the lime being placed below an untreated acidic layer (Figure 15, left), which continues to act as a barrier to root growth. Only where compaction is also a constraint, may direct injection be worth considering.

**Mouldboard ploughing**
Mouldboard ploughing is usually done to fully invert the soil profile, which can result in very effective weed seed burial, typically achieving weed control in excess of 90%. For lime incorporation, however, some mixing and distribution of the lime through the profile is needed to provide a continuous ameliorated pH pathway from the surface soil into the subsoil for root growth. Soil inversion using a mouldboard plough typically results in the lime being buried in a layer at depth together with the topsoil, above which is a layer of acidic soil brought up from the subsoil. Even if the soil is then limed, it can still take some time for this lime to ameliorate the acidic subsurface soil that is now at the surface creating a

**Figure 15 DAFWA Soil profiles of deep-placement lime trials at Maya and South Bodallin stained with universal pH indicator. The purple colour shows poor distribution of the lime (left) and good subsurface distribution (right; additional surface-applied lime can also be seen in the topsoil).**
barrier to root growth. Figure 16 shows an example of where mouldboard ploughing achieved excellent inversion but a thick layer of very acidic subsurface soil \( \text{pH}_{\text{ca}} 3.8-4.2 \) was brought to the surface and despite lime applications before and after ploughing, crop root growth is still being severely restricted by the acidic layer that is sitting above the buried topsoil.

Keeping the mouldboard plough working a little shallower, using a higher speed and setting it up to get incomplete inversion may result in the formation of an angled limed topsoil layer that goes from the surface to subsurface and provides a pathway for root growth into the subsoil. This will compromise weed control and the value of this approach to incorporate lime needs to be weighed up against the costs and compared to other incorporation methods such as rotary spading.

Mouldboard ploughing has proven to be successful for incorporating lime in sandplain soils with mild to moderate subsurface acidity but should be used with caution in more strongly acidic soils.

**Rotary spading**

Rotary spading is a very effective method for deep incorporation of lime to depths of 30–35cm. The spades bury some topsoil while also lifting seams of subsoil to the surface. While the mixing is not thorough or even throughout the profile, there is good distribution of lime right through the cultivation depth with many areas of higher pH where the lime has been mixed into the subsoil (Figure 17).

This mixing action will also improve the contact of the lime with the acidic soil resulting in more rapid and effective neutralisation of the acidity in the soil. Because lime is mixed through a greater volume of acidic soil, higher rates of lime may need to be applied for effective neutralisation of the acidity and the opportunity for lime to move below the cultivation depth.

**Figure 16 Poor distribution of lime after mouldboard ploughing at Wongan Hills can be clearly seen where universal pH indicator has stained limed soil purple and green. Lime has subsequently been applied to the surface to treat the acidic subsurface soil that now covers the limed topsoil.**
Applying lime (continued)

Figure 17 Rotary spading achieved good distribution of lime (stained purple and green by universal pH indicator) in the soil profile and amelioration of soil acidity to 35cm at Miling.

Usually it is recommended to take the opportunity to incorporate lime when you are spading to ameliorate non-wetting soil rather than to undertake spading for lime incorporation alone. In soils with an extremely acidic profile, spading may be the only realistic option for recovering the pH to reasonable levels. Careful consideration of the costs and benefits need to be undertaken to assess whether or not this would be a cost-effective option.
**Shallow incorporation**

Some farmers use shallow incorporation of 200–300kg/ha of lime at seeding. This may be a convenient way to fit maintenance liming into the farming schedule. Soil testing should be done every few years to ensure sufficient lime is being applied to maintain topsoil pH$_{ca}$ at or above 5.5. DAFWA research shows that low rates of lime that do not maintain the surface pH$_{ca}$ at 5.5 or above are insufficient to treat ongoing subsurface acidification. This would not be an effective method of recovering acidic soil as insufficient lime is applied.

Shallow incorporation of appropriate rates of lime using offset discs can be beneficial. The cost is 70–80% cheaper than for rotary spading, although the incorporation depth is only 10–12cm. The advantage over surface application is the mixing and faster neutralisation, leading to more opportunity for the lime to then move deeper into the profile (Figure 18).

*Figure 18 Shallow incorporation of lime using offset discs achieved good distribution of the lime (stained purple and green by universal pH indicator) and was effective in quickly ameliorating topsoil acidity at Badgingarra.*
Timing of liming

It is sometimes difficult to fit liming into an already busy schedule. Most liming is carried out in autumn after summer soil testing results have been analysed. While there is some benefit of incorporation during sowing or working-in by stock of lime applied earlier, if time is a constraint, liming at other times should be considered.

Spring liming is a good option for pasture and allows the workload to be spread (Figure 19). Soil microbes responsible for the breakdown of soil organic matter and mineralisation of nitrogen are inhibited by acidic soil (see 'Soil microbial activity', page 46). Liming in spring allows benefit from the warm, moist conditions, which favour microbial activity. Spring liming of pastures allows time for the lime to start neutralising soil acidity before a cropping rotation, particularly if there is summer rainfall.

Controlled traffic farming systems may provide an option to lime paddocks in crop.

Figure 19 Spring liming of pasture at South Bodallin.Inset: Lime falling onto the pasture is not harmful.
Complementary strategies

The rate of soil acidification due to agriculture can be reduced but not eliminated—liming will always be needed to prevent the soil from becoming too acidic.

Acidification rate

The inefficient use of nitrogen fertiliser is a major contributor to soil acidification in WA. Inputs of nitrogen fertiliser can be managed to reduce nitrogen leaching and this is especially important in high rainfall areas. Required amounts of nitrogen fertiliser should be carefully calculated and split applications may be an option. Non-acidifying or less acidifying nitrogen fertilisers (Table 2, page 14) should be considered. The cost-effectiveness of non-acidifying options compared to other nitrogen fertilisers used in conjunction with appropriate liming should be assessed.

Removal of produce also contributes to soil acidification and some products are more acidifying than others because more alkalinity is exported from the paddock (Figure 20). Usually, it is desirable to maintain maximum crop and pasture choice and apply lime to counter soil acidification. However, if soil is already highly acidic, the choice of less acidifying options (Table 1, page 13), in conjunction with a recovery liming program, may help.

Figure 20 Hay production at Greenhills. Hay production (especially legume hay) removes relatively large amounts of alkalinity from the paddock.
Complementary strategies (continued)

**Tolerant crops and pastures**

The impact of soil acidity can be reduced by choosing crop and pasture species or varieties that are tolerant of low soil pH (Figure 21). Strains of symbiotic nitrogen fixing bacteria also vary in tolerance to acidic soil. Legume crops and pastures should be inoculated with the appropriate strain to ensure the most effective symbiosis in your current soil conditions.

These strategies should be used in conjunction with a liming program to recover soil pH to target values (at or above pH_{Ca} 5.5 in the topsoil and 4.8 in the subsurface). Without treatment, the soil will continue to acidify, the cost of amelioration will increase and all the while productivity and rotation options will continue to be lost.

The full value of liming acidic soil can only be realised when other constraints to growth are also removed.

**Nutrition**

Changing the soil pH by liming can change the availability of nutrients (which is mostly beneficial, see 'Nutrient availability', page 45). Following liming on soils with poor trace element fertiliser history, tissue analysis of growing crops is recommended. In cereals, check for zinc and copper deficiency, in particular, and in lupins, stem test to check for manganese deficiency. Foliar applications can rectify deficiency prior to the application of the appropriate fertiliser.

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**Figure 21** Relative tolerance of crop and pasture species to soil acidity and aluminium toxicity.

*New varieties become available regularly—check current varieties*
Other constraints

If production is still reduced after adequate lime has been applied and there has been enough time for it to work, there is likely to be another constraint to production. Knowing what constraints to production are present across the farm will allow prioritisation of paddocks for treatment and appropriate timing of operations, which can improve the value of treatments.

In WA, soil is commonly both acidic and compacted—constraints which can be treated in complementary operations (see ‘Liming techniques, page 20). Production on soils with acidic and compacted profiles improves when both constraints are removed. A DAFWA ripping and lime incorporation trial at Maya on an acidic and compacted soil profile showed that optimal root growth was only possible on the limed and ripped treatment (Figure 22). Where only one constraint was treated a barrier to root growth remained and roots were confined to the top 20 cm of soil.

Figure 22 A DAFWA trial at Maya showed that wheat root growth proliferated only where both acidity and compaction constraints were removed (right).
Benefits of maintaining an appropriate soil pH profile

It is not always desirable to see a response to liming because this indicates that production has been lost.

Production benefits

Since most agricultural soils in WA are already below the recommended targets, treating soil acidity to remove it as a production constraint often produces a yield response. Wheat yields in WA increase by 12% on average after the application of 2t/ha or more of good quality lime to acidic soils (Table 6).

The time taken to observe this response depends on many factors, such as: the starting pH profile; the amount, frequency and quality of lime applied; the sensitivity of the rotation; and the degree of reliance on subsoil moisture at the end of the season.
Table 6. Average crop grain yield responses to surface-applied lime as the % yield change compared to unlimed control plots for DAFWA soil acidity trials.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Lime rate (t/ha)</th>
<th>Grain yield response (% yield change)</th>
<th>0 years after liming</th>
<th>1–4 years after liming</th>
<th>5+ years after liming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>1–1.5</td>
<td>1 (16 trials)</td>
<td>8 (34 trials)</td>
<td>6 (11 trials)</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>2–2.5</td>
<td>2 (19 trials)</td>
<td>13 (35 trials)</td>
<td>12 (18 trials)</td>
<td></td>
</tr>
<tr>
<td>Canola</td>
<td>1–3</td>
<td>21 (3 trials)</td>
<td>15 (18 trials)</td>
<td>12 (7 trials)</td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>1–3.2</td>
<td>-4 (1 trial)</td>
<td>7 (18 trials)</td>
<td>47 (5 trials)</td>
<td></td>
</tr>
</tbody>
</table>

Gross margin of the paddock

Compare the potential profits from crops that can be grown when pH is not limiting to low pH constraining both yield and choice of crops/pastures in the rotation. Also consider the 'lime' cost of acidity caused by the rotation from nitrogen fertiliser leaching and product removal. Increases in grain yield or pasture production as a result of liming are an indication that productivity has been lost.

Asset value

Liming improves land value. Liming has a long-term value and investment in lime to improve soil pH should be considered in much the same way as fertiliser history when buying or selling farming land.

Lime costs

The pH of the soil profile, lime quality, soil type and farming system will determine the amount of lime required to raise pH to, or maintain pH at, the desired level. For example, clays are

Typically, amelioration and potential responses can take four or more years after liming.

In DAFWA trials, there is consistently little or no yield response for wheat in the year of lime application, but on average, there is a yield increase in the following years. Canola appears to have a large initial response to liming, although this has only been looked at in a limited number of field trials (Table 6). For all crops in Table 6 with sufficient lime and time to treat subsurface acidity, responses are significant. Where pasture is a part of the rotation, production is usually increased after liming.

Profitability

The profitability of liming will differ according to individual circumstances and many factors need to be taken into account.
Benefits of maintaining an appropriate soil pH profile (continued)

slower to acidify but require more lime to lift pH, while sands have less capacity to resist pH change but amelioration requires less lime.

**Time required to change pH**
The initial soil pH profile and soil type are important. Topsoil pH responds quickly to liming (1–3 years). Provided that sufficient lime is applied to raise and maintain the topsoil pH above 5.5, surface-applied lime usually takes four to ten years to treat acidity in the subsurface layers, depending on the depth and severity of the subsurface acidity. Limes with a high proportion of fine particles increase pH quicker.

**Liming interval**
Repeat applications of lime need to be determined by monitoring the change of the soil pH profile over time. The interval will usually be three to seven years depending primarily on initial soil pH and soil type.

Canola crop at Boothendarra. Liming as an integral part of farming practice will maintain crop choice, production and profitability.
Sustainable production and resource protection

Productivity and profitability are usually the immediate concerns to farmers but other issues such as long-term access to markets need to be considered. Some markets insist that farming practices are sustainable—Quality Assured production systems. Maintaining optimum soil pH by appropriate lime use is both environmentally and economically profitable and therefore sustainable.

Long-term prosperity will be enhanced by maintaining the quality of the soil resource. If soil acidification is untreated, the subsurface soils can become highly acidic; amelioration is difficult, expensive and long-term, and all the while productivity is reduced. If pH becomes too low, clay in the soil can be dissolved and soil structural damage can be permanent.

Where acidic soil has reduced plant growth, the susceptibility of the land to wind and water erosion is increased.

Lime delivery at Wongan Hills. Liming to maintain optimal soil pH is necessary to ensure long-term quality of the soil resource.

Such erosion can cause the loss of topsoil, nutrients and soil organic matter.

Applying sufficient lime as an integral part of farming practice is necessary for sustainable production and protection of the soil resource.
Soil acidity has impacts reaching far beyond the farm gate and liming to reduce or prevent on-farm soil acidity will have the offsite benefit of reducing these impacts.

Offsite impacts

Most offsite impacts of soil acidity stem from reduced plant growth leading to less stable soil, poor plant cover and reduced uptake of nutrients and water.

Streams and waterways may be impacted through sedimentation (from eroded soil) and eutrophication (increased nutrients leading to algal blooms). These impacts can result in reduced diversity of aquatic life, particularly if it is an ongoing problem. Degradation of the quality of waterways...
from these impacts can be long-term and have a wide ecological effect.

Modelling of farming systems in the Avon Basin demonstrated that ameliorating soil acidity could reduce nutrient loads in waterways by up to 13%. (Henning & Kelsey 2014). Ameliorating soil acidity and applying nutrients to meet agronomic demand would have even greater benefits, for both waterways and crop production and profitability.

Groundwater is an important natural resource in WA and can be polluted by leached nutrients. More nutrients are leached when acidic soil restricts root growth and therefore nutrient uptake.

Dryland salinity can result from insufficient water usage, which is a greater problem if root growth is restricted and the roots are unable to access moisture deeper in the soil profile. When deep-rooted species are unrestricted in growth, salts remain deeper in the soil and are not problematic.

Possible disadvantages of liming to improve soil pH:

1. Haying-off of crop

This is rarely a problem if the full soil pH profile is appropriate, however it can occur where liming has improved soil pH but acidic soil remains at depth. Increased early water use and large vegetative biomass, as a result of the improved soil pH, can leave inadequate stored soil water for grain filling. This results in haying-off of the crop and reduced yields. The risk of haying-off is increased in:

- dry seasons and seasons with a hot, dry finish
- low rainfall areas/regions (less than 350mm)
- years when there is minimal stored subsoil water
- high input systems with high levels of applied nitrogen driving increased crop vigour and large crop biomass
- years when summer rainfall increases nitrogen mineralisation by soil microbes resulting in increased available nitrogen.

2. Increased activity of detrimental soil microbes

Under more appropriate pH levels, the activity of detrimental soil microbes (as well as beneficial ones) can be increased and may need to be managed.

3. Trace element deficiency

This will only be a problem on soils where insufficient trace element fertiliser has been applied and can be easily rectified in-crop by foliar application and subsequent fertilising prior to the next crop.
Part 2

Chemistry and biology of soil acidity

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Soil pH

A small decrease in soil pH represents a large increase in soil acidity.

The 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, on a negative logarithmic scale (base 10).

The lower the pH, the higher the acidity (Figure 23). Most plants are favoured by a pH between 5.5 and 8. Changes in soil chemistry and microbiology when pH is below or above this range adversely impact plant processes, resulting in reduced growth and yield.

Because of the logarithmic scale, soil with a pH of 4 is 10 times more acidic than a soil with a pH of 5, 100 times more acidic than a soil with a pH of 6 and 1000 times more acidic than a soil with a pH of 7. 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 pHca 4.4 than at 4.8 (Figure 24). This small, 0.4 of a unit, drop from the recommended minimum subsurface pH of 4.8 would result in aluminium toxicity in most WA soils.

Figure 23 Examples of where common substances fit on the pH scale

Figure 24 A small decrease in pH results in a large increase in acidity because the pH scale is logarithmic.
Sandy soils acidify quicker because they have lower buffering capacity but the pH can be recovered faster with the application of less lime than clay soils.

**Soil pH buffering**

The buffering capacity of a soil indicates the capacity of the soil to resist pH change. Hydrogen ions in soil are present both in the soil solution and adsorbed onto the soil surfaces. pH measures the concentration of hydrogen ions in the soil solution. Soils differ in the number of surface sites able to accommodate hydrogen ions. Soils with large numbers of sites able to hold hydrogen ions are able to resist change in the concentration of hydrogen ions in the soil solution and therefore have a high buffering capacity.

Soils with a high proportion of clay or organic matter have a larger number of surface sites able to hold hydrogen ions and are able to resist a decrease in pH. Once acidic, however, highly buffered soils are able to resist an increase in pH. When hydrogen ions in the soil solution are neutralised by lime, hydrogen ions from the soil surfaces are released into the soil solution to maintain equilibrium and resist increase in pH. Better buffered soils are slower to acidify but require more lime to lift pH when they do acidify.

Clays are generally better buffered than loams, which in turn are better buffered than sands (Table 7). Poorly buffered sandy soil types comprise more than 40% of the agricultural land in the south-west of WA (Department of Agriculture and Food, Western Australia 2013).

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.

**Table 7 Rule of thumb indication of the pH change expected from the application of 1t/ha of pure calcium carbonate on different soil types with a starting pH of 4.5.**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>pH change</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>0.5–0.7</td>
</tr>
<tr>
<td>loam</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td>clay</td>
<td>0.2–0.3</td>
</tr>
</tbody>
</table>
In WA, soil pH should be measured in a calcium chloride solution. Water pH values will be higher.

**Measurement of pH**

The most accurate method of soil pH measurement will be achieved in a professional laboratory. 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 (CaCl₂). A ratio of 1 part soil to five parts 0.01M CaCl₂ is used. pH measured by this method is commonly indicated as pH<sub>Ca²⁺</sub>.

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 0.01M CaCl₂ and allows valid comparisons of soil pH between years.

Soil pH measured in water (pH₆₅) can be 0.6 to 1.2 pH units higher than in calcium chloride (Figure 25). 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. It is important to be aware of the method used to determine pH. Many laboratories measure pH in calcium chloride, however, some routinely use water for pH analyses. Field testing is usually done in water or gives a water-equivalent pH value.

When monitoring pH it is very important that you are comparing values measured by the same method and when you are comparing your results to recommended levels, remember to adjust to a calcium chloride pH value if necessary.

Appropriate sampling of soil for pH testing is vital for meaningful results. When inconsistent results, unexpected changes or improbable results occur, the usual explanation is contamination of samples with soil from different depths. It only takes a little limed topsoil to corrupt the results of a 20–30cm soil sample. Sampling with an auger, for example, will not give meaningful results. It is best to use the methods described in ‘Soil sampling’, page 8, or use reputable commercial soil sampling contractors.

Figure 25 Comparison between pH measured 1 part soil to 5 parts water and pH measured 1 part soil to 5 parts 0.01M calcium chloride for WA wheatbelt soils.
Effects of soil acidity

Aluminium toxicity in the subsurface is the major problem associated with soil acidity in WA.

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$_{ca}$ 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. In most wheatbelt soils, aluminium will reach toxic levels when subsurface pH$_{ca}$ falls below 4.8. Aluminium in the soil solution can be toxic at just 2ppm (Table 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 a laboratory analysis.

Toxic levels of aluminium in the soil solution affect root cell division and the ability of the root to elongate (Figure 26). The root tips are deformed. Table 8 Rule-of-thumb indication of the toxicity of aluminium to plant roots.

<table>
<thead>
<tr>
<th>Aluminium in soil solution (ppm)</th>
<th>Toxicity to plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>under 2</td>
<td>not toxic</td>
</tr>
<tr>
<td>2–5</td>
<td>toxic to the roots of sensitive species</td>
</tr>
<tr>
<td>over 5</td>
<td>toxic to tolerant species</td>
</tr>
</tbody>
</table>

Figure 26 Healthy root tip (left) compared to a deformed root tip affected by aluminium toxicity (right). Photos: CSIRO
and brittle and root growth and branching is reduced (Figure 27). Poor crop and pasture growth, crop 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. Liming soil to increase the soil pH is effective in reducing the availability of aluminium to nontoxic levels. Figure 28 shows 11-day old barley seedlings grown in acidic subsurface soil. The seedlings on the left were grown in soil

Figure 27 Wheat seedlings grown in soil with a range of aluminium concentrations demonstrate restricted root growth at high aluminium concentrations. Photo: S Carr

Figure 28 Barley seedlings grown in limed (left) and unlimed (right) acidic subsurface soil; there are no symptoms of aluminium toxicity in the limed treatment.
that was limed to increase $pH_{Ca}$ to 5.1; the available aluminium concentration was less than 2ppm and the seedlings show no symptoms of aluminium toxicity.

The seedlings on the right were grown in the same soil without lime, at a $pH_{Ca}$ of 4; the available aluminium concentration was 15ppm and root growth was severely restricted by toxic levels of aluminium.

**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 nontoxic forms of aluminium. A rough guide to the levels of aluminium can be achieved by measuring aluminium concentration in the same 0.01M CaCl$_2$ solution used to measure the soil $pH$.

The measurement of aluminium in topsoil is further complicated by the

In most cases, the subsurface soil $pH$ will be a good indicator of aluminium levels.

The presence of higher levels of organic matter because aluminium can be bound to the organic matter (and therefore in a nontoxic form) but is released when extracted with the 0.01M CaCl$_2$ solution.

Soil analyses that present aluminium concentrations for topsoil are not meaningful. Even if a high level of aluminium is extracted from the topsoil during analysis, it is unlikely to be available in toxic concentrations in the soil.

At a subsurface $pH_{Ca}$ above 4.5 aluminium concentration is usually less than 2ppm. As $pH_{Ca}$ falls below 4.5, aluminium concentrations increase rapidly and quickly become toxic to most crop and pasture species.

(Figure 29). A $pH_{Ca}$ of 4.8 or above in the subsurface will avoid aluminium toxicity in a wide range of soils for most crop species.
Deficiencies of major plant nutrients often occur in acidic soil because nutrients are less available to plants.

**Nutrient availability**

The availability of nutrients to plants is altered by soil pH (Figure 30). 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.

In addition to being chemically less available to plants, nutrients may also be positionally less available due to poor root growth in acidic soils. When root growth is restricted, plants are unable to explore sufficient soil volume to compensate for the reduced chemical availability. In this case, more nutrients than should be necessary would be required for optimal plant growth, however reduced root growth into the subsoil would still limit access to water deeper in the profile.

A 2012 DAFWA trial at Wongan Hills showed that applying lime, increased the plant uptake of phosphorus (Figure 31). This indicates that soil acidity reduced the availability of phosphorus even though it was present in the soil. Additional phosphorus (20kg/ha) only increased wheat grain yield where lime was also applied (Figure 32) (Scanlan et al. 2013).

Phosphorus levels in many WA south-west agricultural soils now exceed more than is required for optimal production, however over 50% of these soils are also below pH 5.5, which can reduce uptake of phosphorus and other nutrients (Weaver and Summers 2013). 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, aluminium toxicity is usually the only problem resulting from the increased availability (see ‘Aluminium toxicity’,
Effects of soil acidity (continued)

page 42). 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.

Like plants, the functioning of soil microbes is impaired by acidic conditions. Pasture legumes may fail to persist in acidic soils.

Soil microbial activity

Most microbial processes, including the breakdown of organic matter and cycling of nutrients, are reduced in acidic soil because growth and reproduction of the soil microbes, primarily bacteria and fungi, are reduced. Microorganisms break down organic matter and use the carbon and nutrients for their own growth. Nutrients excess to requirements are released into the soil where they are available to be taken up by plants. The rate of mineralisation of nutrients by soil microbes into plant-available forms is
slower in acidic soil, potentially limiting plant uptake.

Importantly, nodulation of sensitive legumes can fail if the soil is too acidic. Legumes are a group of plants that fix their own nitrogen from the air through a symbiotic relationship with specialised bacteria. Under favourable conditions, nitrogen-fixing rhizobia bacteria form a symbiosis with crop and pasture legumes in root nodules (Figure 33).

Acidic soils limit both root growth and rhizobia survival, reducing the chances of roots contacting enough bacteria to form a nodule and inhibit the performance of nodules that do form. In acidic soils, the failure of a functioning symbiosis results in plant 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 sensitive 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.

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.
Nitrogen that stays in the system does not contribute to soil acidification, for example, nitrogen added to the soil as fertiliser is taken up by a plant and then returned to the soil when the plant dies and decomposes and is taken up by another plant and so on (Figure 34).

Ammonium-based fertilisers are the major contributors to soil acidification, especially if the nitrogen is leached rather than taken up by plants. Even if the nitrogen is taken up by plants, ammonium fertilisers contribute some acidity to the soil (only if the nitrogen is returned to the soil again when the plant dies is there no acidification).

Ammonium nitrogen from fertiliser or soil organic matter is readily converted to nitrate and hydrogen ions by bacteria in the soil. This contributes different amounts of hydrogen ions to the soil, depending on the fertiliser.

When nitrate, which is negatively charged, is taken up by plants, a hydroxide ion, also negatively charged, is released from the plant to maintain electrical balance. This hydroxide ion combines with a hydrogen ion in the soil to form water (the hydrogen ion is no longer contributing to soil acidity). Depending on the fertiliser, all hydrogen ions released by nitrification may be neutralised or there may be a net increase in hydrogen ions.

If nitrate is not taken up by plants, it can leach away from the root zone, meaning that no hydroxide ion is released from the plant to bind with a hydrogen ion. Nitrate ions are readily leached from most WA agricultural soils because there are more negatively charged surface sites on soil constituents than positively charged surface sites (required to retain the negatively charged nitrate ions). If nitrate leaches, a positively charged cation is also leached to maintain electrical balance. The cations that leach are usually sodium, potassium or
Ammonium-based fertilisers are major contributors to soil acidification.

calcium rather than hydrogen, because hydrogen ions are more strongly held by the soil. If the nitrate is from ammonium fertiliser, the result is a net increase in hydrogen ions.

Figure 34 shows how ammonium and nitrate fertilisers enter the nitrogen cycle in different places. Nitrification by bacteria of one molecule of diammonium phosphate (DAP) fertiliser would release three hydrogen ions and two nitrate ions into the soil. If the two nitrate ions were taken up by a plant, two of the hydrogen ions would bind with hydroxide ions released from the plant, leaving one hydrogen ion contributing to soil acidity. If the two nitrate ions leached away from the root zone, all three hydrogen ions would remain to contribute to soil acidity. If nitrate ions taken up by the plant are from potassium nitrate fertiliser, there is a liming effect because hydrogen ions are neutralised in the process. If those nitrate ions are leached, there is no liming effect, but also no soil acidification because no hydrogen ions are contributed to the soil with the fertiliser.

Figure 34 Different nitrogen fertilisers follow different pathways in the nitrogen cycle and different numbers of hydrogen ions are released.
In WA, the two main causes of soil acidification are inefficient use of nitrogen and export of food and fibre from the farm.

Export of produce

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). When a cation is absorbed by a plant, a positively charged hydrogen ion is excreted into the soil to maintain electrical balance. When an anion is absorbed, a negatively charged hydroxide ion is excreted into the soil. Plants absorb more cations than anions, which means that most plant
material is slightly alkaline. In a natural system, when plants die they are decomposed and returned to the soil, balancing the acidity caused by the hydrogen ions.

In agriculture, plant material is removed by grazing or harvest or relocated by the concentration of dung into stock camps, rather than being returned to the soil. This means that there is a net export of alkalinity and residual hydrogen ions remain in the soil contributing to soil acidity (Figure 35). 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 Hydrogen ions added in the carbon cycle contribute to soil acidification (not the removal of base cations).
Part 3

Agricultural lime guide

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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.

Figure 36 Close-up of agricultural limesand from a pit near Dongara.

Figure 37 Limesand mine near Coolimba.
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. Limesand may be screened at the pit, but this is not necessary with some particularly pure deposits.

**Limestone**

Most limestone for agriculture is mined and crushed from coastal deposits of Tamala limestone (Figures 38 and 39).

**Figure 38 Close-up of agricultural limestone from a pit near Myalup.**

**Figure 39 Limestone mine near Denmark.**

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.
Lime sources (continued)

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 40 Close-up of dolomitic lime from pit near Watheroo.

Figure 41 Dolomitic lime mine near Watheroo.

Other liming products
Other types of agricultural lime that 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 57).

Calcium oxide (burnt lime or quicklime) and calcium hydroxide (slaked or hydrated lime) are not recommended for use as agricultural lime. Storage and handling of these products is difficult. They are caustic so skin contact and inhalation need to be avoided. Also, burnt lime reverts to calcium carbonate unless stored in airtight conditions.
Lime quality

Carbonate from calcium carbonate (or magnesium carbonate) neutralises acid in the soil.

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.

The soil chemistry can be simplified into a few steps:

- In wet acidic soil, calcium carbonate ionises (separates) into calcium and carbonate ions.
- The carbonate ions react with hydrogen ions in the soil solution and form bicarbonate ions.
- The bicarbonate ions react with hydrogen ions in the soil solution and form carbon dioxide and water.

The end result is that the soil has more calcium ions on the exchange surfaces of the soil, carbon dioxide is released into the soil air and hydrogen ions that were contributing to acidity are bound in soil water (Figure 42).

In moist soil, calcium carbonate from lime ionises (separates) into calcium and carbonate ions

Ionised calcium binds to soil constituents

Carbonate ions react with hydrogen ions to form bicarbonate ions

Hydrogen ions (causing acidic soil) react with bicarbonate ions to form carbonic acid which immediately dissociates into water and carbon dioxide

Carbon dioxide is released into the soil air

Hydrogen ions that were contributing to soil acidity are chemically bound in soil water

Figure 42 Simplified representation of how lime reacts in soil to treat acidity.
Lime quality (continued)

The key indicators of agricultural lime quality are neutralising value and particle size, regardless of the source.

Neutralising value (NV)
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%. With higher neutralising value, lime can be spread over a greater area, or less tonnes per hectare 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.

Particle size
The size of the lime particles determines how quickly the lime can neutralise acid (Figure 44). Lime with a higher proportion of finer particles has a larger surface area to react with the acid in soil. Research shows that finer limes (a high proportion of particles less than 0.5mm) increase

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Figure 43 Approximately 1.7t/ha of 60% NV lime is required compared to 1.1t/ha of 90% NV lime to achieve the same pH change.

Figure 44 Finer particles of agricultural lime were more efficient in changing soil pH at an application rate of 2.5t/ha (from Cregan et al., 1989).

---
While the quality of agricultural limes can vary widely, high-quality lime is available from limesand, limestone and dolomitic lime sources.

pH faster, 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.

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

With high neutralising value limes, you can buy and transport less for the same pH change.

Convert to 100% NV for equal comparison and discount to allow for differences in particle size and speed of reaction.

Cost effectiveness of limes

When selecting an agricultural lime to treat soil acidity the total cost needs to be considered. This includes the purchase cost at pit, transport cost to paddock and spreading cost; all factors are converted to 100% NV for equal comparison and discounted to allow for differences in particle size and speed of reaction.

Sourcing lime from local suppliers, if available, is generally the best option. The further lime needs to be transported, the more critical high neutralising value becomes. The lime supplier should provide up-to-date particle size and neutralising value
information that will allow calculation of the best value lime.

**Online lime comparison calculator**

A useful tool for calculating and comparing the cost effectiveness of agricultural limes is the Lime Comparison Calculator on the Soil Quality website, soilquality.org.au, (Figure 45).

To allow comparison of the total cost per hectare for the equivalent of 100% neutralising value of lime, the Lime Comparison Calculator takes into account:

- cost of the lime
- cost of transport
- cost of spreading
- particle size distribution of the lime
- neutralising value of each particle size.

![Lime Comparison Calculator](image)

Figure 45 The online lime comparison calculator at soilquality.org.au compares the effective cost of limes.
Comparing limes (continued)

The neutralising values of larger particle sizes are discounted using the values of Cregan et al. (1989) to account for the reduced capacity to change soil pH in the short term:

- The NV of particles under 0.5mm is not discounted.
- The NV of 0.5–1mm particles is discounted by 50%.
- The NV of particles greater than 1mm is discounted by 80%.

The online lime comparison calculator is the easiest way to compare the cost effectiveness of limes. Lime suppliers should provide recent product test results detailing the information required for the calculations.

Figure 45 shows lime X compared to lime Y, a coarser lime with lower overall neutralising value. Even though lime Y is 100km closer to the farm, it is still more cost effective to purchase lime X.

Long-hand lime comparisons

The calculations performed by the lime comparison calculator (Figure 45) can be calculated by hand. Using values for lime X from Figure 45:

1. Calculate the overall per cent efficiency of the lime (EP)

Lime EP = Sum all individual particle size EP

EP for the particle size = % of lime x neutralising value (NV) x particle size discount factor

Lime EP for lime X = **86.9** (Table 9)

Table 9 Calculations to determine the lime EP for lime X from Figure 45.

<table>
<thead>
<tr>
<th>Particle size (mm)</th>
<th>Particle size discount factor</th>
<th>% of lime</th>
<th>NV</th>
<th>% efficiency (EP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–0.125</td>
<td>1</td>
<td>5</td>
<td>90</td>
<td>((5 \div 100) \times 90 \times 1 = 4.5)</td>
</tr>
<tr>
<td>0.125–0.25</td>
<td>1</td>
<td>48</td>
<td>90.5</td>
<td>((48 \div 100) \times 90.5 \times 1 = 43.4)</td>
</tr>
<tr>
<td>0.25–0.5</td>
<td>1</td>
<td>38</td>
<td>94.8</td>
<td>((38 \div 100) \times 94.8 \times 1 = 36.0)</td>
</tr>
<tr>
<td>0.5–1</td>
<td>0.5</td>
<td>8</td>
<td>72.1</td>
<td>((8 \div 100) \times 72.1 \times 0.5 = 2.9)</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>0.2</td>
<td>1</td>
<td>62.5</td>
<td>((1 \div 100) \times 62.5 \times 0.2 = 0.1)</td>
</tr>
</tbody>
</table>

OVERALL EP = SUM OF PARTICLE SIZE EP = **86.9**
2. Calculate the costs

Costs = lime cost + transport cost + spreading cost

In this example, the lime costs $10/t and needs to be transported 250 kilometres (km) to the farm at a cost of 10 cents (c)/km. It can be spread for $8/t.

Costs for lime X = $43/t (Table 10)

3. Calculate the effective cost of the lime on the paddock

Effective cost = (100 ÷ EP) × costs

Effective cost for lime X = (100 ÷ 86.9) × 43 = $49.48

For a lime with 100% efficiency, the effective cost would be the same as the actual cost. For a lime with an overall percentage efficiency of 50, the effective cost would be twice the actual cost.

Table 10 Calculations to determine the costs for lime X from Figure 45.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/tonne ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>lime</td>
<td>10</td>
</tr>
<tr>
<td>transport (at 10 c/km/t for 250km)</td>
<td>25</td>
</tr>
<tr>
<td>spreading</td>
<td>8</td>
</tr>
</tbody>
</table>

**SUM OF COSTS = 43**

The further lime needs to be transported, the more critical high neutralising value becomes.

WA lime suppliers

Approximately 35 agricultural lime suppliers currently service the WA wheatbelt. A 2008 DAFWA survey found abundant high-quality lime sources along the west coast between Perth and Geraldton (Gazey & Gartner 2009). The number of sources diminishes moving south of Perth and east across the south coast to Esperance. Limited numbers of inland sources of varying quality are also available.

Many lime suppliers are members of the Lime WA Incorporated group of independent lime suppliers and operate under the association’s Agricultural Lime Industry Code of Practice. Members of Lime WA Inc. provide standard product information sheets with detailed product information and independent lime quality test results (downloadable from limewa.com.au), which can be used with the lime comparison calculator, online at soilquality.org.au.
Part 4

Case studies in soil acidity management

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The old tennis courts at Tammin........ 86
David and Alex Leake, Kellerberrin

Property information

Average annual rainfall: 310mm

Enterprise mix: cereal-lupin rotation, usually 2–3 years wheat

Predominant soil types: tenasol (yellow sandy earth)

Background

David and Alex Leake established a trial in 1991 to investigate the benefits of liming sand plain soils. Following the Kellerberrin Demonstration Group field walk in 2008 (Figure 46), DAFWA and Precision SoilTech became involved as part of the Wheatbelt Natural Resource Management soil acidity project with funding from Caring for our Country.

Trial treatments and management

In 1991, limesand (neutralising value 90%) was surface-applied to plots (15 x 100m) at 1, 2.5, and 5t/ha and replicated three times with an unlimed
Long-term benefits of liming

plot in each replicate as a control. The trial area was subject to the same management regime as the rest of the paddock. In 2001, 1 t/ha of lime sand was surface-applied to all plots as part of whole-paddock liming. For ease of identification, the treatments are referred to by the initial lime application rates.

Soil pH and aluminium

The starting pH of the trial area, based on soil test results taken around the same time, was 4.8 in the surface and 4.5 in the 10–20cm layer. The soil pH deeper in the soil profile was not measured at the time but is assumed to have been around 5, which is typical for the soil type and cropping history.

In 2009, on the 2.5, 1 and nil t/ha plots, where insufficient lime had been applied, the soil pH profiles were increasingly acidic and aluminium levels increasingly toxic (Figure 47). To recover these soil pH profiles to meet DAFWA targets, an estimated 7–10 t/ha would be required and may take more than years.

On the 5 t/ha plot, where sufficient lime had been applied (6 t/ha in total), the soil pH profile met the DAFWA recommended values 18 years after the initial application. At these levels, aluminium in the subsurface is nontoxic to root growth (Figure 47). Similar results most likely would have been achieved by applying the 6 t/ha of lime in two applications of 3 t/ha over the first 10 years. An additional 2 t/ha of lime

Figure 47 Soil pH and aluminium profiles measured in 2009. Initial lime treatments (as labelled) were in 1991 and an additional 1 t/ha was applied to all in 2000.
over the next 10 years will probably maintain the soil profile at DAFWA targets.

**Wheat and barley grain yields**

The 5t/ha limed plots yielded 0.58t/ha more wheat than unlimed plots in 2008 and 0.55t/ha more in 2012 (Table 11). At $300/t, this represented $174 and $165 extra per hectare respectively.

In 2009, the 5t/ha limed plots yielded 1.52t/ha more barley than the unlimed plots, representing $225 extra per hectare at $148/t for feed barley.

Managing soil pH in this trial returned $560 additional income per hectare over the three crops measured alone.

**Barley and weed biomass**

Barley grain yield increases were not completely explained by the soil pH and aluminium profiles. There was a strong interaction between lime treatments and weed burden with the reduced weed burden on the 5t/ha plots contributing to the increased grain yield. Limed plots produced 60% more barley biomass than unlimed plots and, in addition, unlimed plots contained proportionally more ryegrass than plots limed at 5t/ha 18 years ago (Figures 48 and 49).

Increased crop competitiveness and potentially better herbicide efficiency on soils with good pH combine to fight weeds and reduce the seed bank over years.

---

**Table 11 Average grain yield. Initial lime treatments (as listed) were in 1991 and an additional 1t/ha was applied to all in 2000.**

<table>
<thead>
<tr>
<th>Lime (t/ha)</th>
<th>2008 wheat</th>
<th>2009 barley</th>
<th>2012 wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>t/ha</td>
<td>% of max.</td>
<td>t/ha</td>
<td>% of max.</td>
</tr>
<tr>
<td>0</td>
<td>2.92</td>
<td>0.70</td>
<td>1.64</td>
</tr>
<tr>
<td>1</td>
<td>3.30</td>
<td>1.10</td>
<td>1.74</td>
</tr>
<tr>
<td>2.5</td>
<td>3.20</td>
<td>1.76</td>
<td>1.79</td>
</tr>
<tr>
<td>5</td>
<td>3.50</td>
<td>2.22</td>
<td>2.19</td>
</tr>
</tbody>
</table>

**Figure 48 Crop and weed biomass measured in 2009.**
Long-term benefits of liming (continued)

This enabled the subsurface soil to be maintained at or above $pH_{Ca} 4.8$ to a depth of 50cm and prevented aluminium toxicity.

Increased lime use has many benefits to the farming system in addition to increasing yields. Removing acidity as a constraint increased grain yield and crop competitiveness, reduced weed burden and decreased the risk of soil erosion by increasing biomass cover.

David Leake believes that without liming, his profitability and long term future would be in question. Having seen the benefits of liming, David is committed to an ongoing liming program, re-liming paddocks every 3–10 years depending on the amount of acidification. He sees a good return on investment, maximising the value of his other fertiliser and chemical inputs and improvement in yield continuing 15–20 years after liming.

Figure 49 There was more ryegrass than barley in the unlimed plot, compared to the small weed burden in plots limed at 5t/ha 18 years ago.

Conclusions
Six tonnes per hectare (five initially plus one after 9 years) of surface-applied lime was sufficient to recover topsoil pH and maintain it at or above $pH_{Ca} 5.5$ 18 years after the initial application.
Mal and Justin King, Bindi Bindi

Property information
Average annual rainfall: 360mm
Enterprise mix: crop and pasture
Predominant soil types: deep sands and sandy duplex

Trial treatments
This trial was established in 1996 as a long-term DAFWA demonstration site on a sandy gravel soil. Plots 50 x 200m were treated with surface applications of 1 and 2t/ha limesand. Control plots were unlimed and all treatments had three replications.

In 2005 the existing plots were further divided with new liming and deep ripping treatments to test the value of placing lime in the subsurface using modified deep-ripping equipment. A shallow leading tine ripper coupled to a multi-spreader with a venturi distribution system was used to place lime in the subsurface. The leading tine placed lime at 15–20cm and the

Harvesting the long-term large-scale trial established in 1996 at Bindi Bindi.
following tine placed lime at 20–25cm. Tine spacing was 450mm (Figure 50).

The new treatments were:
1. no extra lime added to the original treatments, not deep-ripped
2. no extra lime added to the original treatments, deep-ripped to 25cm
3. surface application of 1.5t/ha lime, not deep-ripped
4. 1.5t/ha lime deep-placed during deep ripping to 25cm.

The trial was managed by Mal and Justin King as part of normal paddock operations.

**Impact of surface-liming**

**Soil pH**

Initially, the soil pH profile was below targets of \( p\text{H}_{\text{cs}} \) 5.5 in the surface and 4.8 in the subsurface and required liming to recover the 0–10, 10–20 and 20–30cm layers to the appropriate pH and prevent aluminium toxicity in the subsurface.

The impact of agriculture on soil pH is clearly demonstrated by comparing the pH in the unlimed plots over time (Figure 51). Where no lime was applied the soil profile continued to acidify and by 2000 was well below appropriate pH. By 2007, eleven years of agriculture without liming had resulted in a severely acidic profile.

Application of 1t/ha of lime in 1996 improved surface pH for a few years but was insufficient to prevent the subsurface from acidifying and by 2004, the whole profile was below target pH. When the pH was measured in 2007, the additional 1.5t/ha of lime that was surface-applied in 2005 had only improved the surface pH to 5.1—still below target and insufficient to recover the subsurface pH, which remained severely acidic (Figure 52).
Figure 51 The soil pH of the unlimed plots became more acidic over time.

Where insufficient lime was applied, the soil pH profile was not sufficiently improved to give a return on the investment in the cost of liming. In 2007, having been above the topsoil target pH for many years, the soil pH for the plots limed at 2t/ha in 1996 was back to the pH levels before liming, indicating that the applied lime had been completely used. Re-liming the 2t/ha plots with 1.5t/ha in 2005 resulted in the soil pH being above target in the topsoil and above critical (pH<sub>Ca</sub> 4.5) in the subsurface by 2007 (Figure 52). Additional lime would have been needed in the following few years to counter ongoing acidification and bring the subsurface to target pH.

Applying lime early was an advantage. Although insufficient, applying 1t/ha lime in 1996 had more impact on soil pH in 2007 than applying 1.5t/ha in 2005.
Surface and deep-placement liming (continued)

Soil aluminium

Soil pH was a good predictor of aluminium levels (Table 12). As a rule-of-thumb, aluminium concentration less than 2ppm is nontoxic, 2–5ppm is toxic to sensitive species and greater than 5ppm is toxic to tolerant species. In 2007, even in plots where the largest amount of lime had been applied, the subsurface soil was below the target of $\text{pH}_{\text{Ca}}$ 4.8 and the aluminium concentration was 2ppm or above. This would restrict the choice of crop and pasture species to tolerant varieties to avoid inhibited root growth.

In the plots where no lime or only 1.5t/ha had been applied in 2005, the lower pH resulted in aluminium concentrations that were toxic and would have inhibited root growth, even of tolerant species and varieties.

Wheat

Wheat grain yield was measured in 1996, 1998, 2004, 2007 and 2009 (Table 13). Surface-applied lime does not usually change soil pH sufficiently in the year of liming to produce a yield response and this was the case in this trial. In subsequent years, the plots limed at 2t/ha in 1996 yielded 10–20% more than the unlimed plots.

A basic economic analysis showed the cumulative benefit of the 1996 2t/ha lime treatment from five years of wheat to be $425/ha. The benefit of the additional 1.5t/ha applied in 2005 from 2 wheat rotations was $250/ha (Table 13).

The benefits of roots being able to grow uninhibited into the subsoil varies from season to season. In years where water is not limiting, there will be less benefit. In the majority of seasons, plants rely on stored subsoil water, which deeper roots are able to access at the end of the season.

Table 12 Average soil $\text{pH}_{\text{Ca}}$ and aluminium concentration measured in 2007.

<table>
<thead>
<tr>
<th>Surface-applied lime (t/ha)</th>
<th>Soil depth 10–20cm</th>
<th>Soil depth 20–30cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{pH}_{\text{Ca}}$</td>
<td>Al (ppm)</td>
</tr>
<tr>
<td>0</td>
<td>4.0</td>
<td>7</td>
</tr>
<tr>
<td>0 in 1996 + 1.5 in 2005</td>
<td>4.0</td>
<td>9</td>
</tr>
<tr>
<td>1 in 1996</td>
<td>4.1</td>
<td>4</td>
</tr>
<tr>
<td>1 in 1996 + 1.5 in 2005</td>
<td>4.1</td>
<td>5</td>
</tr>
<tr>
<td>2 in 1996</td>
<td>4.4</td>
<td>2</td>
</tr>
<tr>
<td>2 in 1996 + 1.5 in 2005</td>
<td>4.6</td>
<td>3</td>
</tr>
</tbody>
</table>

Aluminium was not measured in the 0–10cm layer because organic matter in topsoil causes misleading results.
Table 13 The benefits of surface-applied lime on wheat rotations.

<table>
<thead>
<tr>
<th>Year</th>
<th>Wheat yield (t/ha)</th>
<th>% yield increase</th>
<th>Benefit ($)/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No lime</td>
<td>2t/ha lime</td>
<td>2+1.5t/ha lime</td>
</tr>
<tr>
<td>1996</td>
<td>2.2</td>
<td>2.2</td>
<td>additional 1.5t/ha applied in 2005</td>
</tr>
<tr>
<td>1998</td>
<td>1.6</td>
<td>1.8</td>
<td>11</td>
</tr>
<tr>
<td>2004</td>
<td>2.5</td>
<td>3.2</td>
<td>10</td>
</tr>
<tr>
<td>2007</td>
<td>2.6</td>
<td>2.9</td>
<td>10</td>
</tr>
<tr>
<td>2009</td>
<td>2.0</td>
<td>2.5</td>
<td>2.7</td>
</tr>
</tbody>
</table>

1Using wheat prices at $250/t and not accounting for the cost of limesand. Approximate costs would have been $44/ha for limesand applied at 2t/ha in 1996 and $47/ha for limesand applied at 1.5t/ha in 2005.

Pasture response to liming
Pasture biomass was measured in 2005. The biomass was 70% greater in the 2t/ha lime treatment plot than the unlimed plot. This improvement would have been as a result of improved nodulation of the legume-based pasture and improved availability of nutrients in the topsoil where the pH was appropriate.

Impact of deep-placing lime
Deep-placing lime into the soil using the modified deep-ripper leads to a highly variable soil pH profile because the lime is not thoroughly mixed with the soil. The lime ends up in uneven but reasonably continuous sausage-shaped seams of limed soil through the depth of incorporation. When done correctly, deep-placed lime provides pathways of higher pH soil through the acidic soil to better soil below. This means that soil sampling to test the pH usually does not reflect the impact of the liming.

The impact of effective deep-placement of lime in improving the acidic soil profile can be seen in productivity and yield improvements.

In this trial, deep-placement was only beneficial in the previously unlimed plots (Figures 53 and 54). These plots had the most severe subsurface acidity constraint.

In 2007, the plots that received 2t/ha of lime in 1996 yielded the most wheat grain, regardless of subsequent liming or ripping treatments. In the previously unlimed plots, deep-placing 1.5t/ha of lime in 2005 increased wheat yield to almost as much as the plots that received 2t/ha lime in 1996.

In 2009 the differences in yield between the 1996 treatments were greater and the plots with the best soil pH profile yielded the most grain—2t/ha
of lime in 1996 plus 1.5t/ha in 2005. As in 2007, again in 2009 the deep- placed lime improved wheat yield in the previously unlimed plots but only to around the same as the plots limed at 1t/ha in 1996.

**Conclusions**

The trial site had continued to acidify under a crop – annual pasture rotation where no lime had been applied, resulting in a severely acidic soil profile. In 2007, this site would have required 5–7t/ha of high quality lime over the next 10 years to recover the profile to target pH. Additional costs as a result of ongoing productivity losses would be incurred during the recovery phase.

In contrast, there was a large benefit in the long term from applying sufficient lime in 1996 and then re-applying lime in 2005.

The earlier lime can be applied, the better. Lost productivity and future cost of pH amelioration need to be considered in the medium to long term when making decisions about investing in liming.

If you have very acidic subsurface soil it may be worthwhile incorporating lime to provide pathways of improved soil pH through which roots can grow. The deep-placement method used in this trial is very difficult to get right and of no value if you don’t. Other methods such as rotary spading are probably more suitable (see ‘Liming techniques’, page 20).
Tony White, Miling

3t/ha lime—spaded after surface application
3t/ha lime—surface application only

Property Information
Average growing season rainfall: 230mm
Enterprise: Cropping and livestock
Dominant soil: Yellow sand plain

Background
After extensive subsoil testing for pH, Tony White recognised a significant acidity constraint in the 10–30cm layer. Tony decided to trial incorporation by spading after surface application of limesand on one of his paddocks to speed up the treatment of the subsurface layers.

Trial treatments and management
In 2012, limesand was spread on the surface of the paddock at 3t/ha. The paddock was then spaded to 35–40cm depth, leaving an area approximately 40 x 150m unspaded. The paddock

Figure 55 Spading after surface application of lime improved wheat root growth and yield.
Lime incorporation by spading

was managed as usual and sown to wheat (Figure 55).

Effectiveness of lime incorporation

Visual inspection of small soil pits, stained with universal pH indicator, showed that limed topsoil was reasonably well incorporated by the spading treatment (Figure 56). The distribution of lime was uneven, but there was enough limed soil throughout the acidic 10–40cm layer to provide pathways for roots to grow into the nonacidic soil below. This is reflected in the large spread of pH values at each depth from the replicate samples (Figure 57).

The soil pH profile of the undisturbed limed area was less variable and showed that there was a significant barrier to root growth from 10cm down to 40–50cm with average soil pH_{ca} 4–4.3. Beyond this, soil pH_{ca} increased to around 5 where aluminium toxicity would not constrain root growth.

Figure 56 Incorporation of surface-applied lime by spading effectively distributed the lime through the profile even though the mixing was uneven (areas stained purple and green have higher pH).

Figure 57 Incorporating lime by spading resulted in a variable pH profile but provided pathways for root growth.

Root growth and water usage

In early November 2012 when the crop was ready for harvest, roots in the unspaced profile were present at a depth to 20–25cm. In the spaded
Figure 58 Roots only grew to 20–25cm deep where lime was not incorporated into the subsurface.

Detailed soil sampling showed that the spaded profile was dryer to a depth of 1m (Figure 60). The crop in the spaded area had been able to access and use the subsoil moisture.

Figure 59 Roots were able to grow to 40–50cm deep where lime was incorporated by spading.

Figure 60 Deeper roots were able to extract more soil water. At 50cm the unspaded profile contained significant moisture (top hand), while the spaded was virtually dry. Subsequent soil samples showed that the spaded profile was dryer than the unspaded to more than 1m.
Wheat yield

Deeper rooting depth and therefore access to more subsurface moisture resulted in significantly greater grain yield (Figure 61). The value of the extra 0.7t/ha of wheat is enough to have paid for the lime and spading and the benefits of the improved profile will be ongoing.

![Wheat grain yield (t/ha)](image)

Conclusions

Tony White’s work demonstrates how incorporation of lime by spading can improve crop growth on an acidified soil profile.

Lime applied to the surface at 3t/ha was sufficient to bring the 0–10cm soil pH_{Ca} to almost 5.5, which would have improved microbial activity and nutrient availability in this layer.

In the first year after liming, where the soil was not spaded, the subsurface soil was still very acidic. Over time, some alkalinity from the surface-applied lime will move down the profile and improve the subsurface soil pH. However, this will take many years and require approximately 5t more lime to be applied over the next 10 years to recover the subsurface pH_{Ca} to 4.8.

Incorporation of the limed subsurface soil by spading resulted in a highly variable pH in the subsurface soil but provided pathways of higher pH down to 40cm. Roots were able to grow down these pathways to access subsoil moisture. Tony will need to apply lime to the surface in the future to counter the ongoing acidification that is an inevitable part of agriculture.

Tony did not set out to do a scientific study and there were no areas in the paddock that had no lime and no spading or no lime with spading for comparison. Spading is known to have effects such as removing compaction and distributing nutrients and organic matter. Therefore, we can’t attribute all the improved growth to an improved pH profile. However, there was no evidence of compaction and the root growth and soil moisture observations strongly indicate that pathways of improved soil pH were primarily responsible for the improved crop performance on the spaded areas of Tony’s paddock.

Incorporation of surface-applied lime by spading is a good option to recover very acidic profiles on deep sands.
Alan and Helen Hawley, King River

Property Information

Average rainfall: 762mm
Enterprise: Short horn beef cattle
Dominant soils: Deep sandy and gravelly duplexes and clay loams.

Background

Alan Hawley has tried a number of different innovations to improve his profitability and soil management, however the two that have given the biggest benefits have been planting kikuyu and liming.

Alan was aware that he had a pH problem on the farm. This was evident through soil testing and the pasture composition. As a result he was on the lookout for something that would help deal with the issue.

In the early 1980s Alan went to a DAFWA field day in the South Stirlings area. It was demonstrating the yield increase in crops from applying lime. From this Alan decided to give it a go.

Alan and Helen Hawley have been farming short horn cattle on their property on the King River for nearly 40 years.
Long-term monitoring and liming program

and applied lime to one of his most acidic paddocks.

The response was 'fantastic' with an increase in clover content and size. This motivated him to continue. There was also the potential that he would be able to decrease phosphate applications.

Monitoring

Alan uses Microsoft Excel to record a range of data including his soil test results, fertiliser applications, lime applied and stocking rates. He also uses critical levels to determine nutrient and pH status and has mapped these since 2001. As a result it is possible to see the changes in soil nutrients and pH over many years (Figure 62).

Alan maps his farms by soil/land management unit. He then takes 30–50 topsoil cores from each unit, which he then combines and mixes before taking a subsample for analysis. This makes it easier to sample and analyse by combining similar soil types that are managed in the same way.

In 2013 Alan's farm was mapped under the whole farm nutrient mapping project run by DAFWA (Figure 63). This project funded the sampling and analysis of Alan's entire farm, paddock by paddock for macro nutrients, pH and Phosphate...
Buffering Index. This provided an excellent opportunity to compare the current 2013 mapping results with data from Alan’s innovative mapping and data storage, which goes back to the mid 1980s.

Implementation
Alan’s approach was to apply lime fairly regularly. He aimed to treat the entire farm at least every five years. Rates did vary but they were around 2.5t/ha. This meant that every paddock got one and sometimes two applications in five years, which is roughly the strategy he has been using since the late 1980s.

Over the last five years Alan ramped up his application of lime. He applied an average of 4.3t/ha of lime over the five years across the farm. This did however vary with between 2.5 and 5t/ha applied across the different

Figure 62 Alan Hawley’s mapping of the pH status of his farm shows a clear improvement from 2001 to 2011.
Long-term monitoring and liming program (continued)

paddocks. Rates were based on economics, the pH at the time and future activities, for example, hay crops.

In the late 1980s the topsoil $pH_{ca}$ of the farm was low with paddocks ranging between 3.8 and 4.4. Alan then started to lime the farm regularly and by 2001 the average $pH_{ca}$ across the farm was 4.6, though this did vary between 4.1 and 5.1 (Figure 62). By 2011 the average topsoil $pH_{ca}$ across the farm was 4.8 with at least 50% of the property between 4.4 and 4.8 (Figure 62). This was encouraging, however the pH was still too low.

By 2013 the average topsoil $pH_{ca}$ was 5.3 with paddocks ranging between 4.8 and 5.7. On average the pH increased by 0.5 units over 3 years with the increase in pH varying from 0.2 to 0.9 pH units across the property.

If we look at one area in particular, Hazard Rd paddocks 9 and 10, the $pH_{ca}$ in 1985 was 4.3. Over the next few years the $pH_{ca}$ gradually increased with fairly regular applications of lime to 4.6 by 2011. The cumulative effects of continued liming started to pay dividends and by 2013 the $pH_{ca}$ had reached 5.5 (Table 14, Figure 63).

Total lime application in Hazard Rd paddocks 9 and 10 between 1985 and 2011 was 12.35t/ha which was applied usually in lots of 2.5t/ha using two main

Figure 63 The pH status of Alan Hawley’s farm as mapped by DAFWA whole farm nutrient mapping project in 2013.
Table 14 The topsoil pH of Hazard Rd paddocks 9 and 10 over time.

<table>
<thead>
<tr>
<th>Year</th>
<th>pH&lt;sub&gt;Ca&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>4.3*</td>
</tr>
<tr>
<td>2011</td>
<td>4.6</td>
</tr>
<tr>
<td>2013</td>
<td>5.5</td>
</tr>
</tbody>
</table>

*figure was 5.3 in water

lime sources. A further 2.47t/ha was applied in 2012 which brought the total up to 14.8t/ha since 1985.

The other factor that Alan has considered is the quality of the lime. From 1985–2008 he used lime that had a neutralising value of around 83%. From 2008–2011 he used another source that had a lower neutralising value at around 60%.

Despite the rates being applied, Alan felt that the lime was not ameliorating the acidic soils adequately, which was supported by the apparent drop in average pH from 2008 to 2011. In 2008 the average topsoil pH<sub>Ca</sub> across the farm was 5, however by 2011 it had dropped to 4.8. Alan then swapped back to his normal source of lime and the pH in 2013 was up on average to 5.3, with paddocks ranging from 4.8 to 5.7 (Table 15).

Conclusions

Alan has seen a dramatic change in the quality of his pasture. While there are many factors that can influence this, Alan is sure that part of the change can be attributed to the improvements in soil pH. He now has more clover and rye grass in his sward, which is better

Table 15 Improvements in the topsoil pH<sub>Ca</sub> on Alan Hawley’s King River cattle farm over time.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average pH</th>
<th>Highest pH</th>
<th>Lowest pH</th>
<th>% of paddocks above pH 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>4.6</td>
<td>5.1</td>
<td>4.1</td>
<td>8</td>
</tr>
<tr>
<td>2008</td>
<td>5.0</td>
<td>5.3</td>
<td>4.8</td>
<td>50</td>
</tr>
<tr>
<td>2011</td>
<td>4.8</td>
<td>5.3</td>
<td>4.5</td>
<td>23</td>
</tr>
<tr>
<td>2013</td>
<td>5.3</td>
<td>5.7</td>
<td>4.8</td>
<td>91</td>
</tr>
</tbody>
</table>

Increased soil cover, better weed control, greater persistence of legumes, improved fertiliser efficiency and higher productivity are benefits Alan Hawley has seen from liming to improve soil pH.
Long-term monitoring and liming program (continued)

able to persist in the kikuyu pasture. This has been especially evident on the flats where he had bare areas and large amounts of lotus minor, which has now almost completely been replaced by rye grass and clover.

The other benefit is in the greater availability of nutrients with higher pH. He is able to produce the same amount of feed with less fertiliser and now that the whole farm has been sampled he is more certain of being able to cut back on fertiliser applications by half of current rates, except for hay paddocks.

Now that the pH has reached the target levels Alan is planning to drop lime applications back to maintenance levels. He will still follow the same methodology of liming the entire farm every five years but will drop application rates back to between 1 and 1.5t/ha and will continue to monitor the soil nutrient and pH levels and adjust rates accordingly.

The increases in pH have occurred due to a long-term program of liming. Some amount of variability has occurred, however since the 1980s there has been a general upwards trend. This has shown that even in paddocks with pH_{Ca} as low as 3.9 it is possible to bring them up to an acceptable level and reap the rewards.

Regular monitoring has been the key to success. He has been able to identify the issue, apply the solution and where necessary adjust his approach. This would not have been possible without regular rigorous soil testing, information storage and management.

Liming will continue to be an integral part of farming on Alan Hawley's cattle farm at King River.
The old tennis courts at Tammin

Figure 64 The old grass tennis courts at Tammin provide a quirky pasture demonstration site showing the impact of continuous fertiliser applications and product removal (mowing) on acidification and the response to the chalk used to mark the lines.
Background
For years, the grass tennis courts at Tammin were kept ready for use by regular fertilising, mowing and marking of the lines with chalk. After they were decommissioned and left unkept, the lines of the courts were still marked by growth differences in the grass (and invading weeds) (Figure 64).

Acidification and liming
The two major causes of soil acidification, product removal (mowing) and nitrate leaching (from fertiliser) would have acted to acidify the soil of the courts. This can be seen in the off-line pH values in Table 16. The soil profile is acidic down to at least 30cm. In the topsoil, the availability of all major nutrients would be reduced. The activity of beneficial microbes would be reduced and if any legumes had come in as weeds, nodulation would be poor. In the subsurface, aluminium would be toxic and root growth restricted. It is not surprising that the growth of the grass and weeds is so poor.

Chalk used for marking lines on tennis courts is primarily calcium carbonate and acts in the same way as agricultural lime. Consequently, the pH of the soil on the lines is much higher than off the lines. The topsoil is a quarter as acidic on the lines compared to off the lines, but even so, is well below pH Ca 4.8 and would not be causing aluminium toxicity. The roots of the plants would be able to explore a greater depth of soil to access moisture and nutrients than the roots of plants off the lines.

Table 16 Average pH of soil ‘on’ and ‘off’ the lines at the old Tammin tennis courts.

<table>
<thead>
<tr>
<th>Sample depth (cm)</th>
<th>Soil pHCa on lines</th>
<th>Soil pHCa off lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>4.3</td>
<td>3.9</td>
</tr>
<tr>
<td>10–20</td>
<td>4.9</td>
<td>3.6</td>
</tr>
<tr>
<td>20–30</td>
<td>5.5</td>
<td>3.8</td>
</tr>
</tbody>
</table>

higher. The subsurface pH on the lines is above the target for agriculture of pH Ca 4.8 and would not be causing aluminium toxicity. The roots of the plants would be able to explore a greater depth of soil to access moisture and nutrients than the roots of plants off the lines.

Sampling on the lines of the old tennis courts at Tammin.
Part 5

Frequently asked soil acidity questions

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Lime and lime quality questions

Which lime should I buy?
The best lime is the cheapest per unit of neutralising value purchased, delivered and spread on your farm. Sometimes it is better value for money to transport a higher quality product further. If you are liming to recover acidic soil, a high proportion of fine particles is important.
Simply follow these steps:
1. Soil test at 0–10, 10–20 and 20–30cm to determine where, and at what rate, you need to lime.
2. Obtain product information sheets from suppliers (download from limewa.com.au).
3. Gather costs for lime, cartage and spreading.
4. Use the lime comparison calculator at soilquality.org.au to compare the total cost of effective neutralising value delivered and spread on your farm.

What is the difference between a Lime WA Inc. supplier and others?
Lime WA Inc. members follow the voluntary code of practice. They regularly test their product at approved laboratories and provide a standard product information sheet (see limewa.com.au). The product information sheet openly displays the range of test results for the lime source, indicating the consistency of the product.

What are the regulations governing the quality of agricultural lime?
Lime is described in the Biosecurity and Agriculture Management (Agriculture Standards) Regulations 2013 as 1st grade or 2nd grade. The groups are too broad for farmers to make a cost-effective decision on quality. DAFWA recommends that growers source product information sheets from Lime WA Inc. suppliers (limewa.com.au).

What is the difference between the different kinds of lime?
Limesand, limestone and dolomitic lime (dolomite) are the most common agricultural limes. They are natural, mined

Spreading fine lime at Williams. Lime with a larger proportion of fine particles will raise soil pH quicker.
products comprised mostly of calcium carbonate with some magnesium carbonate.

Liquid lime sources are generally micro-fine calcium carbonate in suspension. The quality and effectiveness of these limes should be considered in the same way as other agricultural limes in terms of their capacity to change soil pH.

Burnt lime or quicklime is produced by heating (burning) calcium carbonate materials, such as limestone, to above 825°C, causing chemical changes and forming calcium oxide. Hydrated or slaked lime is produced by adding water to calcium oxide, forming calcium hydroxide.

Calcium oxide and calcium hydroxide are not recommended for use as agricultural lime because they are difficult to handle and store. They are caustic and can burn skin if contacted and cause respiratory problems if inhaled. Burnt lime reverts to the more stable calcium carbonate unless stored in airtight conditions.

When would I use dolomite in preference to other limes?
To raise your soil pH, you should use dolomite if it is cheaper to purchase, transport and spread on your farm an equivalent amount of effective neutralising value compared to other sources.

Does the extra magnesium in dolomite cause any problems?
No. Limesand and limestone are generally 1–2% magnesium and dolomite around 10%.

Is limestone better than limesand?
No—the capacity to change soil pH is governed by the neutralising value of any source of lime. The lime supplier should always provide product test results on neutralising value and particle size. How quickly lime can neutralise soil acidity is determined by particle size. Regardless of the source (limesand, limestone or dolomitic limestone), finer particles react quicker.

What is the best way to rate lime quality?
Neutralising value and particle size are the key indicators of lime quality. Limes with a higher neutralising value will treat more acidity in the soil and limes with a higher proportion of fine particles will treat the soil acidity quicker. Lime suppliers should provide recent product test results. Members of the Lime WA Inc. group of lime suppliers adhere to the voluntary industry code of practice and provide detailed product information sheets, downloadable from limewa.com.au.
Lime and lime quality questions (continued)

How much does agricultural lime quality vary?
Agricultural lime quality, as measured by neutralising value and particle size, can vary a lot between sources. The consistency of the product from individual suppliers can also vary as they are natural products. An indication of the variability can be gained from the range of previous tests presented on Lime WA Inc. members’ product information sheets.

How much difference is there in buying wet lime compared to dry lime?
It can make a large difference. Water will add to the weight and increase transport costs without adding any neutralising value. Most people buy lime after harvest and before seeding when it is most likely to be drier.

How can I test the neutralising value of my lime?
Neutralising value of lime can only be accurately tested in a laboratory. Lime WA Inc. suppliers use either ChemCentre in Bentley, WA or Agrifood Technology in Bibra Lake, WA.

Is it calcium or carbonate that does the work?
Definitely the carbonate. Essentially the carbonate (CO₃⁻) from the calcium carbonate (CaCO₃) (lime) reacts with the acid in the soil (H⁺) to give carbon dioxide (CO₂) and water (H₂O). If you add agricultural lime to vinegar (weak acid but stronger than the acidity of your soil) it will react and fizz to give carbon dioxide (the bubbles), water and calcium ions. This is just a fast version of what happens in the soil.

Can I store lime in the paddock?
Yes, if you need to. It is best to get the lime spread as soon as possible but if it is necessary to store it in the paddock, coating with a 1:5 mixture of ammonium fertiliser dissolved in water via a fire-fighting rig to form a protective crust should prevent erosion of the fine particles. Commercial coating agents are also available.

See ‘Part 3 Agricultural lime guide’, page 52, for more information on lime and lime quality.

Mining limesand at Green Head. Limesand, limestone and dolomitic lime are natural mined products.
Liming questions

Why do I need to lime?
What happens if I don’t lime?
What is the effect of soil acidity?

All forms of productive agriculture cause soil acidification. Removal of alkalinity from the farm in produce and the acidifying effects of ammonium fertilisers leaves the soil more acidic (low pH) (see ‘Causes of soil acidity’, page 48). Aluminium toxicity in acidic subsurface soil restricts root growth and access to subsoil water. Low soil pH can also reduce the availability to plants of essential plant nutrients and the activity of beneficial microorganisms (see ‘Effects of soil acidity’, page 42).

Adequate applications of agricultural lime can maintain soil pH or recover acidic soil to appropriate levels, preventing production loss due to soil acidity (see ‘Benefits of maintaining an appropriate soil pH profile’, page 30).

Why can’t I see a response to the lime I applied?
There are several reasons why responses to liming are not observed:

- Insufficient lime (quantity and/or quality) has been applied to remove acidity as a production constraint.
- There has not been enough time for the lime applied to treat acidity in the subsurface (often takes at least four to seven years).
- Another constraint, such as compaction, is preventing optimum production.
- The lime is acting to maintain an already good soil pH profile. This is the most desirable outcome because no production has been lost due to soil acidity.
Liming questions (continued)

Can I lime at any time of year?
Which is best, liming pasture in winter or before the crop in March?
What is the value of applying lime in spring?
Liming has a long-term benefit and can be carried out at any time it fits into the farming schedule. In a tramline farming system the time of application doesn’t matter because you won’t be damaging crop or pasture when spreading in-crop. Ultimately, the earlier you apply lime the sooner you see the benefits. Spring liming of pastures can be beneficial to a following cropping rotation as there is time for the lime to start neutralising acidity, particularly if there is summer rainfall (see ‘Timing of liming’, page 26).

Can I burn stubble after liming?
The temperatures reached during stubble burning will not affect lime. After burning, there is less protection against wind erosion, which could result in the loss of recently spread lime on the soil surface.

Why do sheep eat the stubble off lime trials first?
Where liming has removed soil acidity as a constraint to production, the crop and subsequently the stubble, will have had better access to water and nutrients and be more palatable to sheep.

Can I spread wider with limestone?
The coarser limestone particles will spread further, but they are less reactive and effective application rates will be uneven, resulting in poor treatment of soil acidity. Spreading width should be 6–8m (depending on wind conditions) to get good coverage of fine particles.

Tramline farming at Buntine. Tramline farming can make it easier to apply lime whenever it fits into the farming schedule.
If the soil pH is appropriate (see the Kellerberrin and King River case studies, page 68 and page 80).

**Why is it recommended to apply lime over 5–10 years?**

**Is it better to apply a larger amount of lime at once, or less more often?**

**Is it possible to put on too much lime at once?**

Surface-applied lime takes a long time to treat acidity in the subsurface soil and the amount of lime required can only be estimated. If large amounts of lime are recommended, it is sensible to apply some of the lime at first and retest after 3–4 years to refine the estimate of lime requirements.

High rates of lime are unnecessary for maintenance of soil pH, but may be beneficial in recovering acidic soil. High rates of lime will neutralise soil acidity quicker and once the acidity has been neutralised, the lime dissolves only very slowly. This remaining lime will continue to treat the ongoing acidification that results from farming (see 'Maintenance liming', page 13 and 'Recovery liming', page 14).

Applying high rates of lime where some of the micronutrients including manganese, zinc and copper are marginal, may induce deficiencies that can be overcome by the application of appropriate solid fertiliser or foliar spray (see 'Nutrient availability', page 45).
Liming questions (continued)

If I have a paddock at pH 4.8 and another at 5.3, which gets priority?
This choice is complicated and it depends on the subsurface pH. You need to test the soil at 10–20 and 20–30cm as well as the topsoil. To maintain farm income, lime to maintain the better-performing paddocks or recover the profile to appropriate pH if subsurface acidity is limiting production. A liming program can be developed to include liming the less productive paddocks in the future.

Remember that soil acidification will continue in paddocks under agriculture and more lime will be required to recover soil pH. It is important that adequate lime be applied to treat acidity in the surface and subsurface soil (see ‘Developing a liming program’, page 12).

What rate of lime do I apply in a paddock with variable pH?
If the paddock is not uniform, management areas can be based on soil type and the pH profile. Soil sampling should be representative of these areas and lime can be applied where it is needed according to the soil pH profile. It is better to apply more lime in areas of low soil pH, and less where the pH is higher, rather than a single rate over the whole paddock. For example, if some areas of a paddock required 2t/ha and some required 3t/ha, a strategy could be to apply 2t/ha to the whole paddock, recheck pH in three years and apply 1t/ha to the areas which required 3t/ha (see ‘Liming effectively’, page 16).

Why is 2–8 t/ha of lime often recommended now? This seems more than previously.
Over the last 20 years (since the old 1t/ha in 10 years recommendation) the soil profile has continued to acidify because, generally, production has increased due to improvements in agricultural practices and insufficient lime has been applied to counter the increased acidification. More lime is now required to treat and recover the more acidic soils. Liming programs need to account for existing acidity in the soil profile and ongoing acidification due to agriculture. Soil type, rainfall and farming practice need to be considered in addition to the pH of the soil profile.

At what pH should we start putting out lime? What is an acceptable low pH?
It is best to maintain pH_{Ca} at or above 5.5 in the topsoil and 4.8 in the subsurface. If the topsoil pH_{Ca} falls below 5.5, there will be insufficient alkalinity to move down and treat subsurface acidification. The best practice is to sample and test the soil every three to four years and apply lime if the pH falls below targets. At pH_{Ca} 4.8 in the subsurface root growth won’t be affected by aluminium toxicity. Remember that it may take several years after liming to recover
acidic subsurface soil and all the while acidification will be continuing due to farming and production will be lost.

**Lime is my second largest expense per hectare after nitrogen, what strategies have I got?**
You need to develop a liming program based on soil testing at 0–10, 10–20 and 20–30cm. If you can’t lime everywhere that needs it, give priority to your best performing paddocks. Apply enough lime over a 5–10 year period to raise the pH<sub>c</sub> of the topsoil to 5.5 and the subsurface soil to 4.8.

**How do I get a return on liming?**
**What is the return on investment time?**
The return and return time on investment in liming will depend on individual circumstance. The value of liming should be considered as value of production not lost. An increase in production in response to liming means that production has been lost. Maintaining soil pH at the DAFWA target levels will prevent loss due to soil acidity (see ‘Appropriate pH’, page 12). If the benefits of liming are to be fully realised, it is important to remove other constraints to production such as subsurface compaction.

**On leased farms with low pH, how do I prioritise whether to lime or not?**
The benefits of liming are long-term and add value to the property. Liming is often required or negotiated as part of

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Soil profile stained with universal pH indicator at Hyden. The orange colour indicates an acidic layer at about 10–20cm with appropriate pH below (green). Soil profiles that have an acidic layer will usually be corrected quicker following liming than a profile that is acidic to depth. In this case a compacted layer would have to be removed before the full benefit of liming could be realised.
a lease agreement. On soils with low pH, particularly if the subsurface is also acidic, it may be several years after liming before production benefits are realised.

How do I get lime to move down the profile faster?
Surface-applied lime can take a long time to treat subsurface acidity. The key to minimising the time is to apply enough lime. The most important thing is to keep the surface pH$_{Ca}$ above 5.5. If the pH falls below this, alkalinity from the lime cannot move down the soil profile. Even if your surface pH is at 5.5, you need to test the subsurface at 10–20 and 20–30cm so that you know how much lime you need to treat acidity in these layers. So long as you keep the surface pH$_{Ca}$ at 5.5 you can apply the required amount of lime in two or three applications over a few years.

Is it possible to put lime in the subsurface soil where needed if the surface is OK?
Is it possible to get pH change more quickly by deep liming?
Effective deep-placement of lime is difficult to achieve and requires extensive modification of farm equipment (see ‘Direct injection’, page 22). Adequate surface-applied lime will allow alkalinity to move down to treat acidity in the subsurface, although it may take several years to recover acidic soil to an appropriate pH.

If compaction is also a production constraint, applying lime to the surface prior to deep-ripping will be beneficial in incorporating some lime into the subsurface. It is probably not worth the expense of deep-ripping just to incorporate lime (see ‘Surface applied, then deep rip’, page 21).

Spading to incorporate surface-applied lime is a good option on some soils with subsurface acidity (see ‘Rotary spading’, page 23).

A trial at Maya showed the value of surface application of lime prior to deep-ripping.
Care needs to be taken with mouldboard ploughing to incorporate lime. A thorough job of inverting the topsoil can bury your limed topsoil under a layer of acidic subsurface soil, which could require further liming before you can successfully grow anything (see ‘Mouldboard ploughing’, page 22).

**Should I get lime to depth with spading or am I better off spending the equivalent on more lime?**

This will depend on your individual circumstance. If your subsurface soil is very acidic and your soil is suitable for spading, it would be worthwhile looking closely at costs and potential benefits.

If you have a layer of acidic soil constraining root growth, spading after surface application of lime can be very effective at providing pathways of higher pH soil through which roots can grow to the nonacidic soil below. In this case, acidity problems can be overcome in the first year of treatment. Some spaded and unspaded test strips with and without lime would help to determine the benefits (see the Milling case study, page 76).

**At what threshold should we shift to getting lime into the subsoil with spading?**

Again, this depends very much on individual circumstances and you need to carefully assess costs and benefits. If you have a severe acidity constraint, say pH_{Ca} less than 4.5 in the surface 0–10cm and subsurface 10–20 and 20–30cm layers and better pH deeper in the profile, then removing the acidity barrier by spading can provide immediate benefits.

**Does lime ‘leach’ to depth? At what rainfall?**

The movement of alkalinity depends on many interacting factors. Alkalinity will not move down the profile unless sufficient lime is applied to raise the surface pH_{Ca} to 5.5. Movement is usually quicker in higher rainfall zones.

**What rates of lime should be used with deep ripping, spading or mouldboard ploughing?**

The lime will be treating a greater volume of soil in one go so this needs to be accounted for and generally higher rates should be used compared to an initial surface application. The aim is to provide pathways of higher pH soil for the roots to grow through. Once the lime is incorporated into the soil, alkalinity can move deeper, continuing to improve the soil pH profile.

These techniques produce highly variable soil pH profiles so subsequent sampling will have to account for this. Spraying the surface of a small soil pit with universal pH indicator stain will give you an indication of how well the lime has been incorporated.
How were the DAFWA pH targets determined?
Would a surface pH 6 and subsurface 5 be better?
Should I be getting topsoil pH to 6 to get more lime
down the profile?

The DAFWA targets of pH_{ca} 5.5 in the 0–10cm and 4.8 in
the 10–20 and 20–30cm layers were based on the work of
Whitten (2002) and many years of trial data. These
are the minimum pH values that are appropriate. Soil pH
values are usually an average of a number of samples and
therefore improving the pH further will mean that a greater
proportion of the soil is above the minimum, resulting in
better movement of alkalinity down the profile. Soil microbial
activity and nutrient availability would also improve.

A topsoil pH_{ca} of 6 and subsurface pH_{ca} of 5 would be ‘better’
but you need to work out if the benefits are cost-effective for
your individual situation.

If I keep my topsoil pH above 5.5, why do I need to
test the subsurface?

Liming to maintain the topsoil pH_{ca} above 5.5 will treat
ongoing acidification and allow sufficient alkalinity to move
down and treat subsurface acidification. If the subsurface
soil is already acidic, maintaining topsoil pH_{ca} above 5.5
should prevent further subsurface acidification. However, it
is necessary to also know your subsurface pH because if it
is already acidic, more frequent applications and/or higher

How much lime is required to produce a certain
change in pH or to reach targets?

The amount of lime required will depend on the current pH
profile, soil type, rainfall, farming system and lime quality. To
assist with calculations, pure calcium carbonate (100% NV)
applied at 1t/ha would increase topsoil pH by approximately
0.7 on sand, 0.5 on loam and 0.3 on clay. Greater quantities
of agricultural lime would be required to achieve these
changes, depending on its neutralising value.

We want plants to grow roots to 1–2m, why is 30cm
recommended for sampling?

It is a compromise on money spent on sampling and testing
and money spent on liming. Sampling in 10cm increments to
30cm gives a good guide to the soil profile in most cases.

Agricultural soils that have had insufficient lime applied to
maintain topsoil pH_{ca} at 5.5 usually have an acidic layer
between 10 and 30cm. More recent evidence suggests that
for deep sandy soils where little or no lime has been applied
to continuously farmed paddocks, samples down to 50cm
are necessary to determine a soil pH profile because the
continuing acidification has resulted in lower soil pH deeper
in the profile.
On sandy soils where little or no lime has been applied in the last 20 years, acidity may have developed deep in the profile and sampling to 50cm may be necessary.

Why do I get large differences in my pH from year to year?
Soil pH will gradually decline due to ongoing acidification caused by agriculture but you are not likely to be able to detect this year to year. If you do see unexpected changes from year to year it is most likely due to sampling a slightly different soil type or sampling by a different method resulting in samples from different depths. Different testing methods give different results. pH measured in water will be higher than pH measured in calcium chloride. Different laboratories using different protocols can also give different results. See ‘Diagnosing soil acidity’, page 8, for standard sampling, testing and monitoring methods.

How long after liming should I soil sample?
To observe changes in soil pH as a result of lime application, monitoring should be done 3–4 years after application. If you are liming to recover the pH of acidic soil, make sure
that your initial application is sufficient to raise the pHca of the surface soil to 5.5. In 3–4 years further testing will allow refinement of the estimate of the amount of lime required to finish the job.

**Is there a correlation between pH and soil colour?**
The correlation between pH and soil colour is not very good. There is a better correlation with soil type, with sandy soils generally having a lower pH but this can be quite misleading if lime has been applied. Always soil test.

**Why does aluminium come into solution at low pH? Can it go back out?**
The soil chemistry is complicated. In simplified terms, aluminium, which is a highly reactive element, can take many forms in soil. When soil pHca is above 6, aluminium can be in a solid state, which is usually nonreactive. It can form complexes with ions like sulphate, hydroxides and organic matter in the soil, which react in many diverse ways. When the soil pHca drops below 5, it can be in a soluble form (in the soil solution), which is generally highly reactive.

In general, most soils in WA have sufficient amounts of aluminium (in solid form) that will cause problems to plant growth if the soil pHca drops below 4.8. Solid forms of aluminium dissolve into the soil solution and, in this form, inhibit root growth. When lime is applied to acidic soils, lifting the soil pHca above 4.8, the soluble aluminium precipitates from the soil solution into a biologically inactive (solid) form.

**Can you tie up the aluminium by adding something else to the soil?**
Aluminium is highly reactive, and will readily complex (blend with) many organic and inorganic compounds. Some of these complexes are biologically active (can cause root damage), whilst others are not. Measuring these is very complex, and makes universal soil tests almost impossible. In terms of binding aluminium into biologically inactive forms, the application of lime is universally the cheapest option. The application of organic matter (e.g. animal manure) will result in the formation of both soluble and insoluble organic complexes. These are usually biologically inactive, but this method is rarely a long-term solution.
A-horizon — see topsoil

Acid — A substance that releases hydrogen ions.

Acid soil — Sometimes used instead of acidic soil to describe soils with low pH. Take care not to confuse with ‘acid sulphate soils’, which is a very different issue than soil acidity generated by agriculture.

Acidic soil — In WA agriculture, soil is considered acidic if the pHca is less than 5.5 in the top 10 cm or less than 4.8 below 10 cm.

Acidification (of soil) — The process of soils becoming acidic. A natural process, which is accelerated by agriculture.

Acidification rate — Describes how quickly the soil is becoming acidic.

Agricultural lime — Any substance used to treat acidic soil. In WA it is usually a mined product—limesand, crushed limestone or crushed dolomitic lime, which are comprised primarily of calcium carbonate with varying amounts of magnesium carbonate.

Alkaline — Describes a substance that has the ability to neutralise acid. Plants can be considered alkaline because if they are eventually returned to the soil to decompose and continue through the carbon cycle, there is no net acidification of the soil. However if they are removed, hydrogen ions contributed to the soil during the uptake of nutrients are not balanced and contribute to soil acidity.

Alkaline soil — Soil with a pH greater than 7. In agriculture, alkaline soil is not usually problematic below about pH 8.

Alkalinity — Refers to the alkaline properties of a substance.

Aluminium toxicity — In agricultural soil, aluminium present in the soil solution to a level detrimental to root growth.

Ammonification — A process which releases ammonia or ammonium compounds from nitrogenous soil organic compounds as a result of the action of bacteria.

Anions — see ions

Available nutrients — Nutrients in the soil solution that can be readily absorbed into plant roots. The availability of nutrients is is affected by many factors, including soil pH, and usually the total amount of a nutrient in the soil is greater than the available amount.

B-horizon — see subsoil

Base — A substance that has the ability to combine with hydrogen ions.

Biomass (of plants) — The total weight of above-ground plant material.

Buffering capacity (of soil) — The capacity of soil to resist change in pH from the addition of acids or bases.
Burnt lime or quicklime — Burnt lime or quicklime is calcium oxide which has been formed by heating calcium carbonate materials, for example, limestone, causing chemical change. Usually used in manufacturing industries.

Calcium carbonate, \( \text{CaCO}_3 \) — The chemical compound that is the primary component of agricultural lime. The carbonate from calcium carbonate neutralises acidity in soils.

Calcium chloride, \( \text{CaCl}_2 \) — A chemical compound that readily dissolves in water. A weak calcium chloride solution is used to mix with soil prior to measuring pH to minimise the variability in results due to seasonal conditions.

Cations — see ions

Caustic — A substance able to burn or corrode by chemical action.

Cementation — Permanent bonding of soil material into a rock-like form.

Compaction — An increase in the density and strength of soil and associated reduced porosity. In WA agriculture it is primarily caused by the action and traffic of farm machinery.

Cretaceous chalk — A form of limestone which can be crushed and used as agricultural lime.

Cycling of nutrients — Nutrient cycles are the routes taken by nutrients from their source, through soils, plants, animals and microorganisms and back to the source. In agriculture many cycles are ‘broken’ through leaching of nutrients and the removal of produce.

Deep-placed lime — Agricultural lime that has been placed in the subsurface soil by the direct injection method.

Deep-ripping — Deep tillage using rigid tines to physically break-up compacted subsurface soil to improve drainage and root penetration.

Direct injection — A method of delivering a product (lime) into the subsurface soil layers behind deep ripping tines.

Diversity (of species) — Diversity indicates the variety of species in a particular area and takes into account the total number of species and how common a species is compared to other species in the area.

Dolomitic lime, dolomite — Agricultural lime mined from ancient inland drainage systems and containing a higher percentage of magnesium carbonate than limestone or limesand.

Eutrophication — The process whereby mineral nutrients are increased and dissolved oxygen is decreased in a body of water, resulting in an environment favourable to algae and plants and unfavourable to animal life.

Exchange sites — Areas of positive or negative charge on soil particles that attract anions and cations. Anions and cations can be exchanged from these sites for other anions and cations in the soil solution.
Geo-located, geo-location — Sites that have a location description using GPS.

GPS, Global positioning system — a system that uses satellites to accurately describe the location sites.

High rainfall areas — In the WA agricultural region, high rainfall areas receive over 450mm annual rainfall.

Hydrated lime or slaked lime — Hydrated lime or slaked lime is calcium hydroxide, produced by adding water to calcium oxide.

Hydrogen ions, H⁺ — Positively charged hydrogen atoms. The concentration of hydrogen ions determines the pH of the soil. Also see ion.

Ion, ions — An atom or group of atoms that have an electrical charge. This electrical charge is caused by the loss or gain of one or more electrons.

Anion: a negatively charged ion, e.g. nitrate ion, NO₃⁻.

Cation: a positively charged ion, e.g. hydrogen ion, H⁺; calcium ion, Ca²⁺.

Leaching — In agriculture, the downward passage of free water containing ions, such as nitrate, through the soil and out of the root zone.

Legume nodulation — Formation of the association between legume roots and bacteria resulting in a 'nodule' on the roots and leading to fixation of atmospheric nitrogen.

Lime (agricultural) — see agricultural lime.

Limesand — Agricultural lime mined from coastal dunes, predominantly comprised of calcium carbonate with some magnesium carbonate.

Limestone — Agricultural lime mined and crushed from coastal deposits, predominantly comprised of calcium carbonate with some magnesium carbonate.

Liming — In agriculture, adding agricultural lime to the land to treat soil acidity.

Maintenance liming — In WA agriculture, adding sufficient agricultural lime to counter the ongoing acidifying effects of agriculture and maintain soil pHₑₒ at or above 5.5 in the surface and 4.8 in the subsurface.

Marl/marlstone — A sedimentary material comprised of clay and calcium carbonate. Lakebed marl and marlstone (hardened marl) can be mined, crushed and used as agricultural lime.

Microbe — see microorganism

Microbial activity — In agricultural soil, the various actions and normal life processes of microorganisms, for example, mineralisation of nutrients, nodulation of legumes, infection of plants with diseases.

Microorganism — In agricultural soil, bacteria, fungi and other microscopic life which may be beneficial (e.g. in nutrient cycling and legume nodulation) or detrimental (e.g. disease pathogens).
Mineralisation — The release of elements (nutrients) from soil organic matter to forms that plants can take up as a result of microbial processes.

Molecule — Two or more atoms held together by electrostatic and electromagnetic forces, for example, one calcium, one carbon and three oxygen atoms form one molecule of calcium carbonate, CaCO₃.

Mouldboard plough, ploughing — A plough that lifts and rolls the topsoil over so that it drops back to the ground upside down into the furrow left by the leading cutting blade of the plough.

Negatively charged ion — see ion

Neutralising value, NV (of agricultural lime) — A percentage describing the capacity of the lime to neutralise soil acidity relative to pure calcium carbonate, which is given a value of 100%. Agricultural lime with a NV of 50% can neutralise half that of the same quantity of pure calcium carbonate.

Nitrification — The oxidation of ammonium compounds in soil (from fertiliser or released from organic compounds) and conversion to nitrites and nitrates as a result of the action of nitrifying bacteria. See also ammonification and mineralisation.

Nitrogen-fixation — The conversion by rhizobia bacteria of atmospheric nitrogen to forms that can be taken up by plants. This process is enabled as a result of a symbiotic relationship between the bacteria and legume plants. See also nodulation.

Nodulation, nodule — The formation of a small outgrowth (nodule) on the roots of legume plants as a result of infection with rhizobia bacteria, which form a symbiotic relationship with the plant. See also nitrogen-fixation.

Nutrient availability — see available nutrients

Nutrient mapping — Detailed soil nutrient test results are mapped to the geographical location. Colour coding allows visual assessment of nutrient status and creation of zones and can be used for variable rate fertiliser application.

pH, pH₉, pH₄ — Describes the acidic or alkaline property of a substance, with pH 7 being neutral.

pH₉: soil pH measured using 1 part soil to 5 parts 0.01M calcium chloride solution.

pH₄: soil pH measured using 1 part soil to 5 parts water.

In WA agriculture, soil is considered acidic if the pH₉ of the top 10cm is below 5.5 or the subsurface 10–20, or 20–30cm is below 4.8. Plant growth is favoured by a topsoil pH₉ between 5.5 and 7.5.

Phosphate Buffering Index, PBI — Describes the ability of soil to hold phosphorus. Soils with a high PBI quickly bind applied phosphorus to exchange sites, leaving it unavailable to plants; soils with low a PBI hold only small amounts
of phosphorus, leaving most of the applied phosphorus available to plants, but also subject to leaching.

Plant-available nutrients — see available nutrients
Positively charged ion — see ion
Quick lime — see burnt lime

Recovery liming — In agriculture, adding sufficient agricultural lime to ameliorate acidic soil and raise the pH to, or above, 5.5 in the surface and 4.8 in the subsurface. The pH change in the subsurface may take many years and require more than one surface-application of lime. Incorporation of lime may produce a quicker increase in pH.

Rhizobia bacteria — Bacteria that form a symbiotic relationship with legumes. The rhizobia fix atmospheric nitrogen, which is used by the plant, and receive carbohydrates and proteins from the plant. See also nitrogen-fixation, nodulation.
Root nodule — See nodulation
Root zone — The area in which roots are found in the soil profile.

Rotary spading — Mechanical mixing of soil to approximately 30–40cm.

Salinity (dryland salinity) — The build-up of salts in the soil and groundwater in non-irrigated land.

Sedimentation, siltation — The process of depositing sediment over the bottom of waterways resulting in the build-up of fine particles and also an increase in the suspended sediment in waterways. In agricultural areas, sedimentation of waterways is usually caused by water erosion. This results in smothering of plant and animal life and clogging of pore spaces in the natural sediment.

Sensitive crops — Crop species or varieties with an decreased capacity to cope with the effects of a stress.

Silica sand — Sand sized particles derived predominantly from silica.
Slaked lime — see hydrated lime

Soil acidification — see acidification (of soil)
Soil acidity — see acidic soil
Soil microbe — see microorganism

Soil organic matter — The components of soil that are derived from plants, animals and microorganisms.

Soil profile — The layers of a soil. Usually refers to the soil horizons (see topsoil, subsoil) but may be used to describe the soil in terms of other properties such as soil pH.

Soil solution — The water in the soil containing dissolved salts, gasses, and soluble organic compounds. Plants take-up nutrients from the soil solution.

Spading — see rotary spading
Subsoil, B-horizon — The soil below the topsoil or A-horizon. Contains less soil organic matter and more clay than topsoil and may consist of more than one layer.

Subsurface acidity — Low pH soils occurring in the 10–20 and 20–30cm layers; can also occur deeper.

Subsurface constraint — A restriction to root growth occurring in the 10–20 and 20–30cm layers; can also occur deeper.

Subsurface soil — Soil below the top 10cm of soil, independent of the depth of topsoil or change in horizon. Usually refers to the 10–20 and 20–30cm layers of the soil profile. See topsoil, subsoil.

Surface liming — Application of a liming material broadcast onto the soil surface, usually without any subsequent incorporation other than normal tillage operations.

Surface soil — The top 10cm of soil, independent of the depth of topsoil or change in horizon.

Symbiosis — An association between two organisms providing mutual benefit, for example, legumes and rhizobia bacteria.

Tamala limestone — The geological name given to the limestone deposits along the Western Australian coast from Shark Bay in the north to nearly Albany in the south. Deposits of calcium carbonate shells from marine organisms were formed into limestone rock by compression and cementation.

Target pH — The minimum appropriate pH for agriculture in the south-west of WA.

Tolerant crops — Crop species or varieties with an increased capacity to cope with the effects of a stress.

Topsoil, A-horizon, surface horizon — The top layer of soil, immediately above the B-horizon or subsoil. Commonly at 0–10cm in the south-western agricultural area in Western Australia. It contains more soil organic matter, nutrients and soil organisms than the B-horizon and is usually visually distinguishable by its darker colour.

Universal pH indicator — A combination of dyes which react and change colour according to pH conditions. This may be used to give an indication of whether accurate soil sampling and testing is required.

Variable rate technology — A method of applying inputs, such as agricultural lime or fertiliser, according to predefined criteria.

VRT — see variable rate technology

Wheatbelt — An area, comprising most of the south-western agricultural area in Western Australia, that is used for broadacre agriculture.
References and resources

Further reading


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Soil acidity: a guide for WA farmers and consultants is a comprehensive, up-to-date guide to managing soil acidity in Western Australia. The guide is user-friendly and rich in examples, diagrams and photographs. The format allows easy selection of appropriate information on the specifics of managing soil acidity, the science behind the problem and finding the best value for money agricultural lime.

This edition contains many new examples and case studies as well as answers to the latest frequently asked questions.

This guide is purpose-written for Western Australian farmers and consultants managing soil acidity and is underpinned by over 30 years of research by the Department of Agriculture and Food, Western Australia.

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