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Soil acidity

A guide for WA farmers and consultants

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A guide for WA farmers and consultants

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Important Disclaimer

Cover photo: Gerry, Kelvin and Clay Kent on their property at Bodallin

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Introduction

Soil acidity is an economic and natural resource threat throughout the Western Australian wheatbelt. 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. Estimates of production loss for the wheatbelt due to acidity range from $300–400 million, or about 10 per cent of the annual crop.

In the Avon River Basin (Figure 1), approximately 80 per cent of topsoils and almost half of subsurface soils are below the pH targets recommended by the Department of Agriculture and Food, Western Australia (DAFWA) (Figure 2). Recent studies indicate that approximately 80 per cent of topsoils in the north of the wheatbelt and 90 per cent in the south are below the DAFWA pH targets. Little current subsurface pH data are available for these areas. However, it is likely that subsurface soil pH is similar to the Avon River Basin.

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

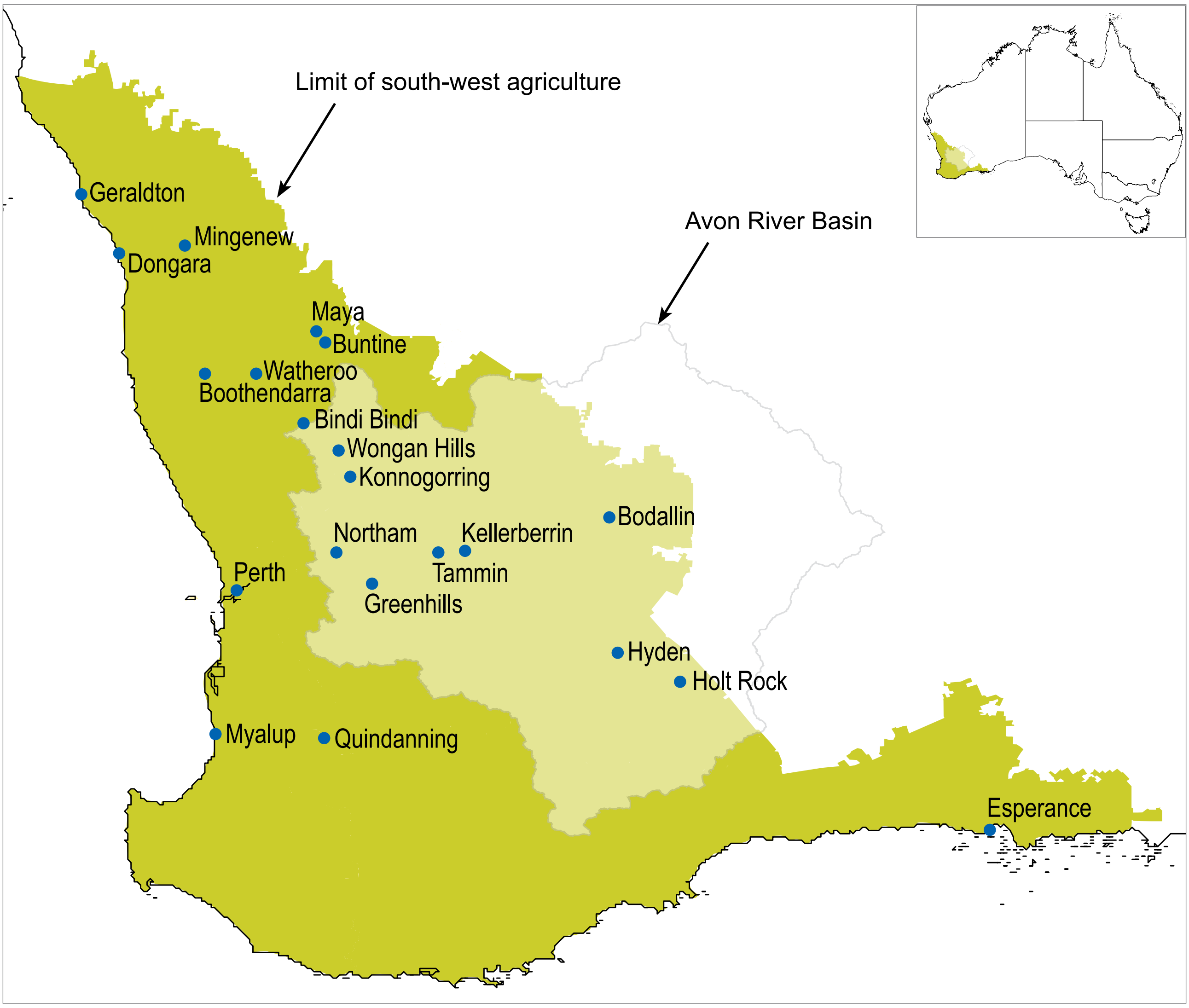


Figure 1 **Location of the Avon River Basin and wheatbelt towns referred to in this guide**

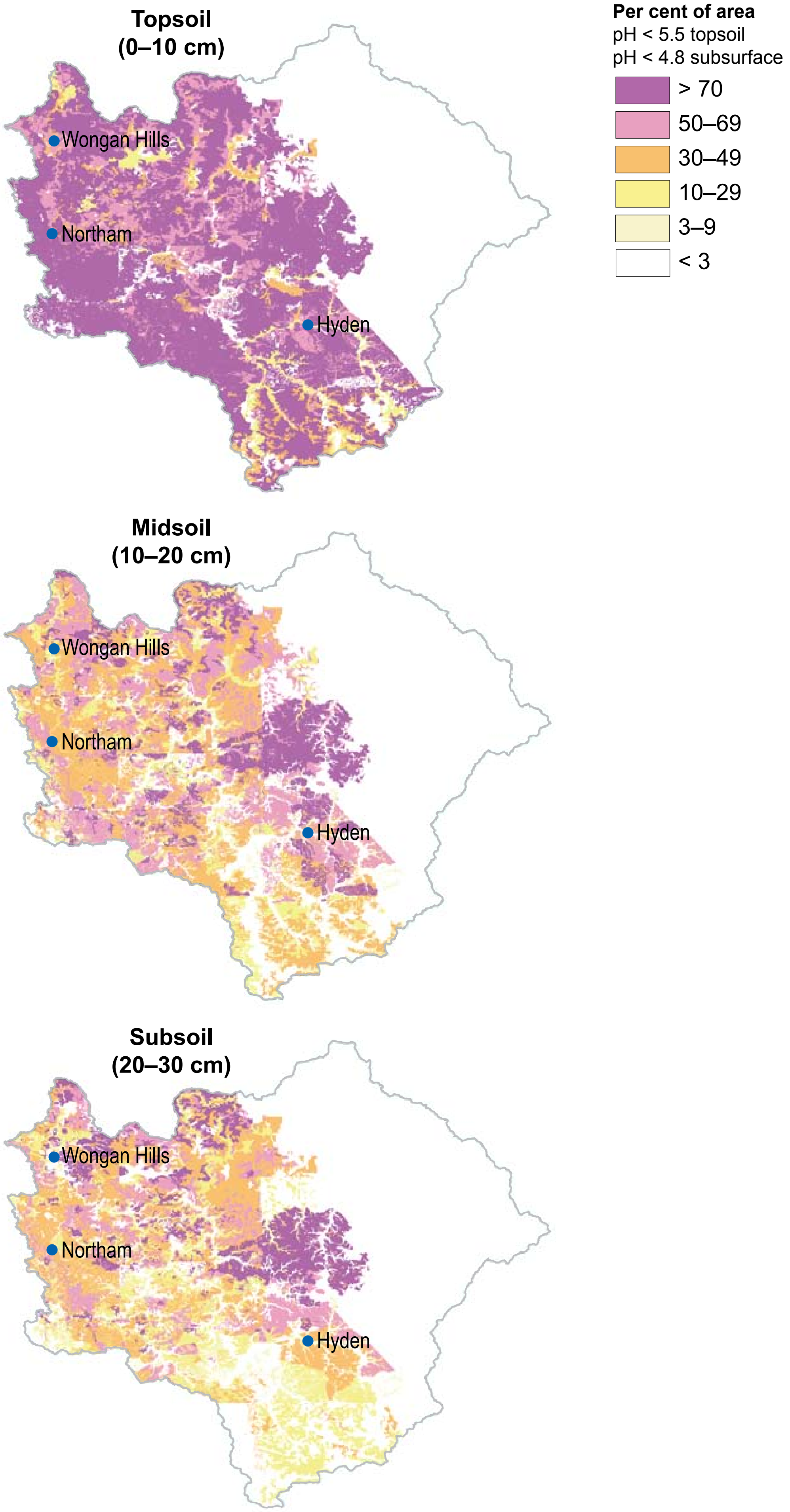


Figure 2 **Percentage area of the Avon River Basin (Figure 1) with soils below DAFWA pH targets**

PART 1

Management of soil acidity

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. Subsurface soil testing to determine the pH profile of the soil is vital. In many soils, an acidic subsurface or acidic subsurface layer may be limiting root growth and access to water and nutrients (Figure 3).

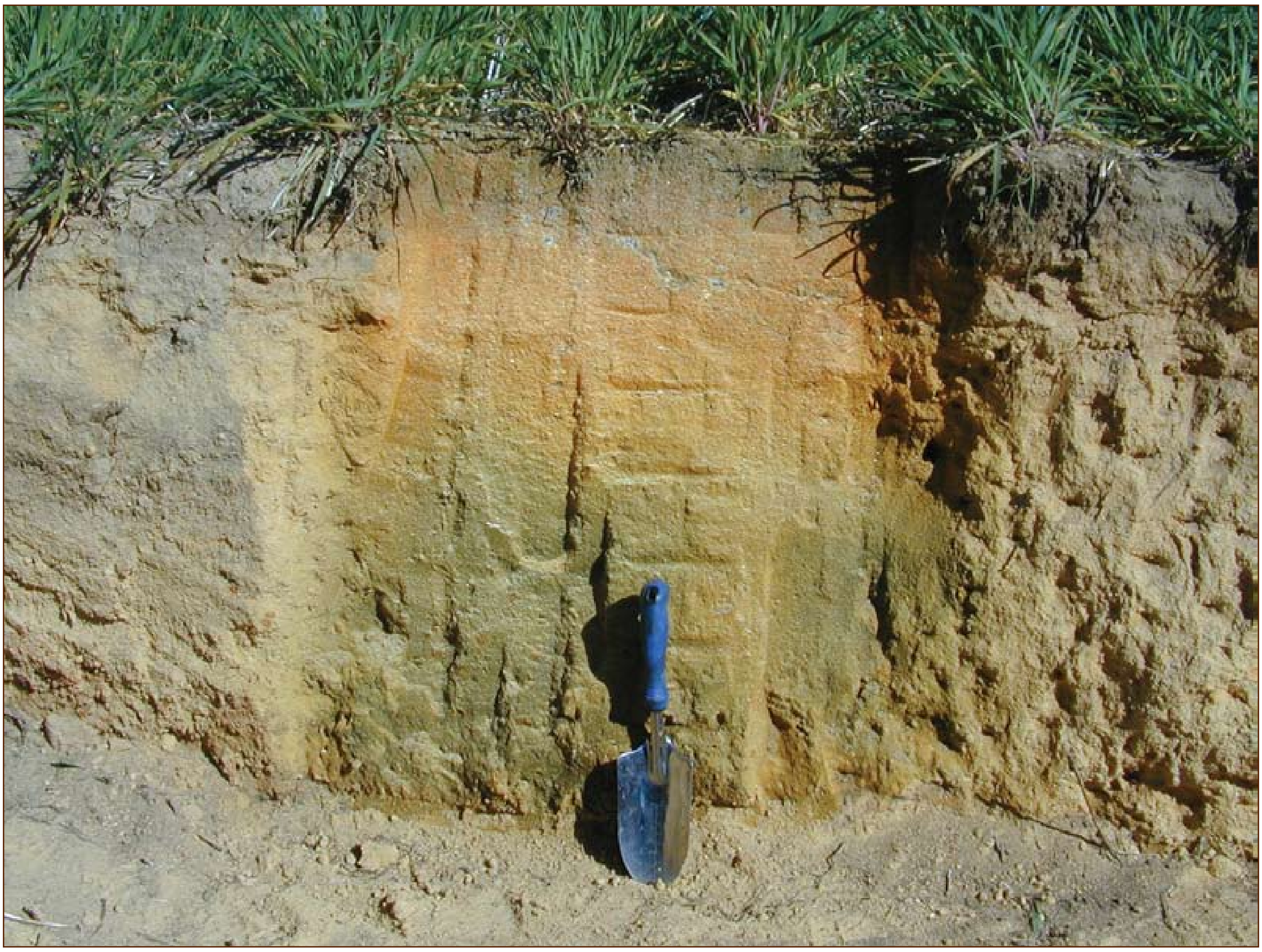


Figure 3 **Soil profile at Tammin stained with universal indicator showing acidic subsurface layer (stained orange) which prevents root access to soil with suitable pH below (stained green)**

Soil sampling

Topsoil pH can be quite different from the subsurface soil pH 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 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 under-sample; 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 4). 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.

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 20–30 cm 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 10 cm of soil. This type of sampler is unsuitable to sample the 10–20 and 20–30 cm soil layers that are necessary for soil pH sampling. A 5 cm diameter exhaust tube, marked in 10 cm increments, is a suitable alternative (Figure 5).

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 M calcium chloride solution (see measurement of pH, page 25).

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

Figure 4 **Soil sampling at Kellerberrin. Professional soil-sampling contractors should be able to accurately sample the soil profile.**

recommendations and accurate record keeping to enable comparable repeat sampling over years for monitoring pH change.

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 20–30 cm 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 instead of 0.01 M 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 to estimate pH 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.

Monitoring soil pH

Monitoring soil pH by re-sampling every three to four years enables liming programs to be developed and refined for individual situations. 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 GPS, to allow comparable repeat sampling.

Sampling 25 per cent 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.

Figure 5 **An exhaust tube marked in 10 cm increments is useful for do-it-yourself sampling.**

Liming acidic soils

Soil acidification is an inevitable and ongoing consequence of productive agriculture. Whether soil becomes acidic depends on how well ongoing soil acidification is managed as part of the farming system.

Target pH

DAFWA recommends soil pH values at or above 5.5 in the topsoil and 4.8 in the subsurface (Figure 6). These values have been developed based on hundreds of trial-years of data. Maintaining topsoil pH 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 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 liming will be required to counter ongoing acidification due to agriculture.

If the topsoil pH is below 5.5, recovery liming is recommended to prevent the development of subsurface acidity, even if the subsurface pH is currently at 4.8. When the topsoil pH 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 is below 4.8, liming to maintain (or recover) topsoil pH 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.

Figure 6 **Discussing the implications of a target pH profile at Casuarina, north of Mingenew**

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.

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.

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

Table 1 **The lime equivalent (as pure calcium carbonate) of various farm products (Moore 1998)**

Product removed	$CaCO_3$ equivalent (kg/t)
Cereal grains: wheat	9
barley	8
triticale	7
Cereal whole tops	20
Canola	2
Lupin grain	20
Lupin whole tops	60
Lucerne hay	60
Hay (mixed grasses)	30
Subclover (whole plant)	40
Sheep: dung	25
urine	9
lambs	3
wool (6 kg/sheep)	0.4

Table 2 **Lime (as pure calcium carbonate) required to neutralise acidity generated by various common nitrogen fertilisers (Moore 1998)**

Nitrogen fertiliser	$CaCO_3$ required to neutralise nitrogen addition (kg $CaCO_3$/kg nitrogen[1])	
	none leached	100% leached
Ammonium sulfate (Agras #1, MAP)	3.6	7.1
Ammonium nitrate (Agran)	0	3.6
Urea	0	3.6
DAP	1.8	5.4
Potassium nitrate	–3.6[2]	0
Sodium nitrate	–3.6	0

[1] Per weight of nitrogen (N) in the fertiliser, not per weight of the fertiliser.

[2] Negative values indicate a liming effect by the fertiliser.

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 7).

The rule-of-thumb guide (Table 3) indicates of the amount of lime that may be required to achieve topsoil pH above 5.5 and subsurface pH above 4.8 after 10 years. 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 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 above 5.5 for alkalinity to move down to treat acidity in the subsurface soil.

Table 3 **Rule-of-thumb lime guide developed for the Avon Catchment Council**

Soil depth (cm)	pH	Lime amount over 5 years
0–10	< 5	2 t/ha
	< 5.5	1 t/ha
		plus
10–20	< 4.5	2 t/ha
	< 4.8	1 t/ha
		plus
20–30	< 4.5	1 t/ha
	< 4.8	measure pH in 3 years

Figure 7 **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.**

Improving liming recommendations

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 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 are often around 2 t/ha but need to be based on soil pH monitoring test results so that the lime can be targeted to management areas within paddocks as required.

Guessing how much lime to apply from only topsoil samples can lead to inadequate lime application (Figure 8). Applying too little lime does not treat subsurface acidity. Yield will continue to be lost as subsurface pH continues to decline and root growth is inhibited.

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

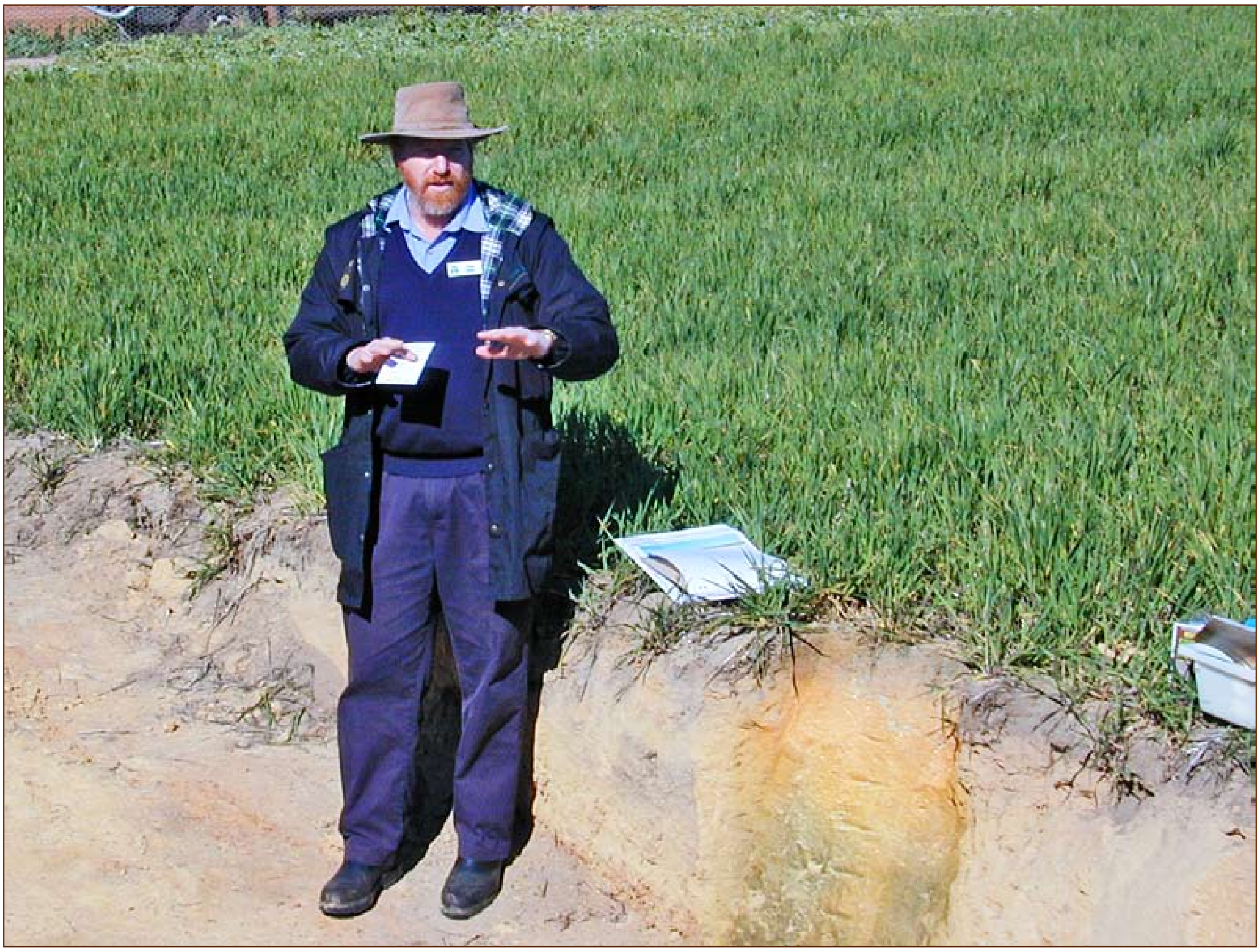


Figure 8 **Soil profile stained with universal indicator at Tammin shows an acidic subsurface layer, stained orange, which would not be detected by only sampling topsoil**

A worked example

The following example is worked from actual pH data from the paddock in Figure 9. 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 liming options were then considered (Table 5): 1. application of 1 t/ha regardless of soil pH; 2. application of the lowest amount from the recommended range based on topsoil pH only; 3. application of the recommended amount based on the soil pH profile.

Figure 9 **The 90 ha paddock used in this example**

Table 4 **Soil pH at six sites in one paddock (Figure 9) and the recommended liming rates when only pH of topsoil or pH of all three depths is taken into account**

Site	Soil type	Soil pH 0–10 cm	Soil pH 10–20 cm	Soil pH 20–30 cm	Recommended lime over 10 years (t/ha): pH from 0–10 cm only	Recommended lime over 10 years (t/ha): pH from 0–10, 10–20 & 20–30 cm
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 using different soil pH information**

Site	Area (ha)	Lime required over 10 years (t): Option 1	Lime required over 10 years (t): Option 2	Lime required over 10 years (t): 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	**90 ha**	**90 t**	**95 t**	**160 t**

***Option 1**—No soil pH values, 1 t/ha lime applied over whole paddock*

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**—Topsoil pH values only, lime applied to targeted areas at the lowest amount 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 the subsurface will continue to acidify.

***Option 3**—pH values from 0–10, 10–20 and 20–30 cm taken into account, lime applied to targeted areas at the recommended rates*

The total amount of lime applied would be 1.8 times more than option 1. The method used would be to immediately spread 2 t/ha on all areas that require liming. Then in two to four years time 1 or 2 t/ha would be spread on the areas which required 3 or 4 t/ha over the 10 year-period. Re-sampling the soil in three to four years would allow adjustment of liming rates as necessary.

How to apply lime

Whether liming to maintain or recover soil pH, surface application (at appropriate rates) is the recommended method (Figure 10). Good results have been achieved with deep placement of lime using modified farm-scale machinery, 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 m (depending on wind conditions) to get good coverage of fine particles (less than 0.5 mm). Spreading too wide results in uneven treatment of soil acidity. Larger particles will spread up to 15 m 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 ploughing and deep-ripping. This enables better distribution of the lime particles and greater contact with the acidic soil. Liming before deep-ripping for compaction adds value to both treatments.

Shallow incorporation

Some farmers use shallow incorporation of 200–300 kg/ha of lime at seeding. Little work has been done to test whether this makes a difference to the rate or amount of amelioration that can be achieved. DAFWA research shows that low rates of lime that do not increase the surface pH to 5.5 or above are insufficient to prevent ongoing subsurface acidification.

Figure 10 **Surface application of lime south of Northam**

Direct injection

This technique deep-places lime during deep-ripping, using modified machinery (Figure 11). Research has shown that successful direct injection is possible (Figure 12, right) and subsurface acidity can be quickly removed as a production constraint. When the distribution of lime is correct, responses of 20–30 per cent 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 12, left) and root growth will still be restricted. Only where compaction is also a constraint, may direct injection be worth considering.

Figure 11 **Extensive modification of machinery is required for good distribution of deep-placed lime.**

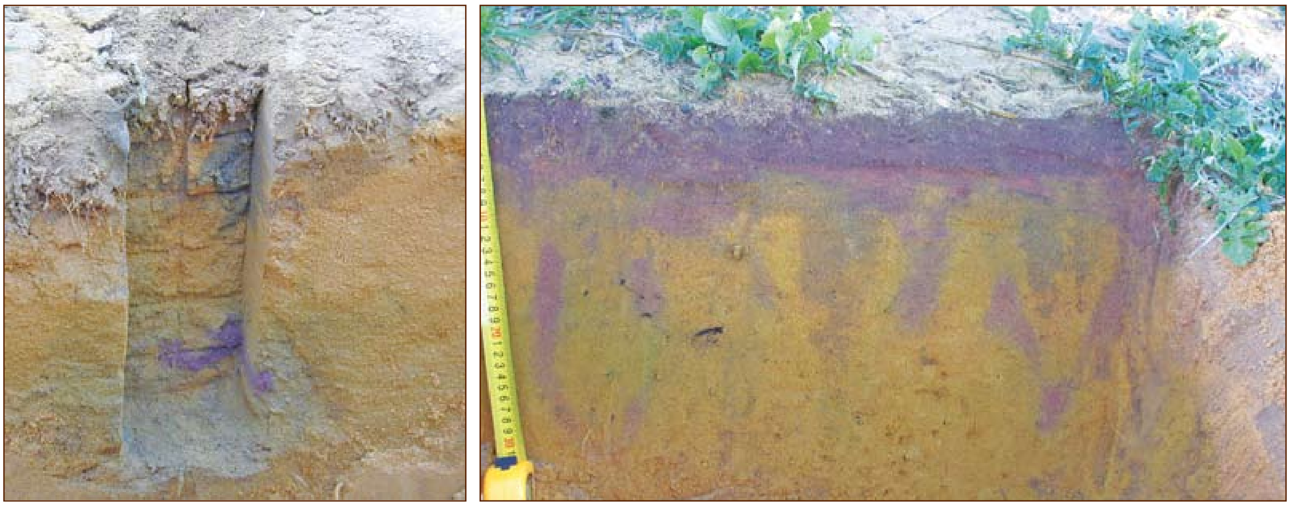


Figure 12 **DAFWA deep-placement lime trials at Maya and South Bodallin. Soil profiles stained with universal pH indicator; purple shows placement of the lime. Poor distribution of the lime (left) is ineffective as an untreated acidic layer remains above and continues to act as a barrier to root growth. Good subsurface distribution of the lime (right) is difficult to achieve; the presence of additional surface-applied lime can also be seen in the topsoil.**

Timing of liming

Most liming is carried out in autumn after summer soil testing results have been analysed. However, it is sometimes difficult to fit liming into an already busy schedule. There is some benefit of incorporation of earlier-applied lime during sowing or working-in by stock. However, if time is a constraint, liming at other times should be considered. With tramline farming systems, lime can be applied at any time without any detriment to the crop.

Spring liming is a good option for pasture and allows the workload to be spread (Figure 13). Soil microbes responsible for the breakdown of soil organic matter and mineralisation of nitrogen are inhibited by acidic soil. 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.

Lime and general nutrition

Changing the soil pH by liming can change the availability of nutrients, which is mostly beneficial (see Nutrient availability, page 28). 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.

Figure 13 **Spring liming of pasture at Bodallin**

Acidification rate

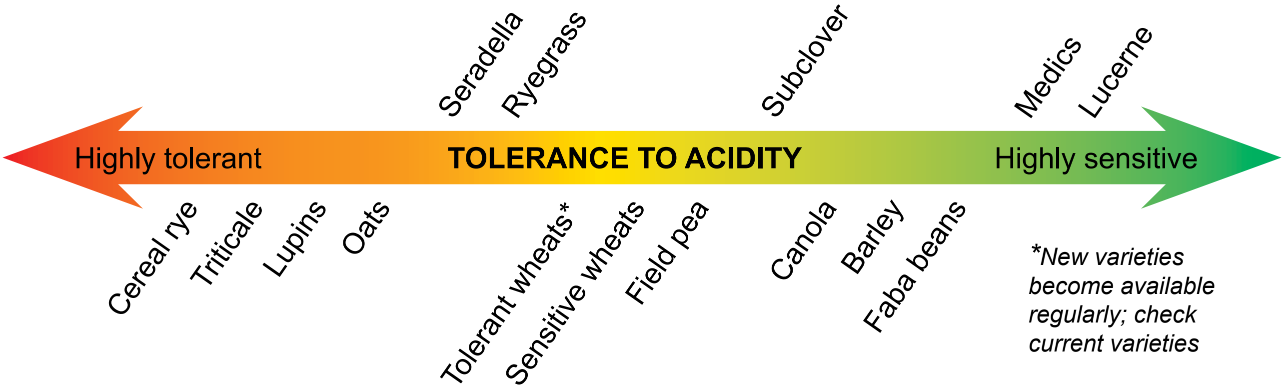
The rate of soil acidification due to agriculture can be reduced but not eliminated—liming will always be needed to prevent the soil from becoming too acidic.

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 8) 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 15). 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 8) in conjunction with a recovery liming program may help.

Tolerant crop and pasture species

The impact of soil acidity can be reduced by choosing crop and pasture species or varieties that are tolerant of low soil pH (Figure 14). This strategy should be used in conjunction with a liming program to recover soil pH to target values (at or above 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.



*New varieties become available regularly; check current varieties

Figure 14 **Relative tolerance of crop, pasture and species to soil acidity and aluminium toxicity**

Figure 15 **Hay production at Greenhills. Hay production (especially legume hay) removes relatively large amounts of alkalinity from the paddock.**

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 (Figure 16).

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 soil is acidic and plant growth is reduced, the susceptibility of the land to wind and water erosion is increased. Erosion can lead to loss of nutrients and soil organic matter.

Figure 16 **Lime delivery at Wongan Hills. Liming to maintain optimal soil pH is necessary to ensure long-term quality of the soil resource.**

Off-site impacts

Soil acidity has effects reaching far beyond the farm gate and liming to reduce or prevent on-farm soil acidity will have the off-site benefit of reducing these impacts (Figure 17). Most off-site impacts of soil acidity stem from reduced plant growth leading to less stable soil, poor plant cover and reduced uptake of nutrients and water.

Sedimentation (from eroded soil) and eutrophication (increased nutrients, algal blooms) of waterways can result in reduced abundance and 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.

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

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.

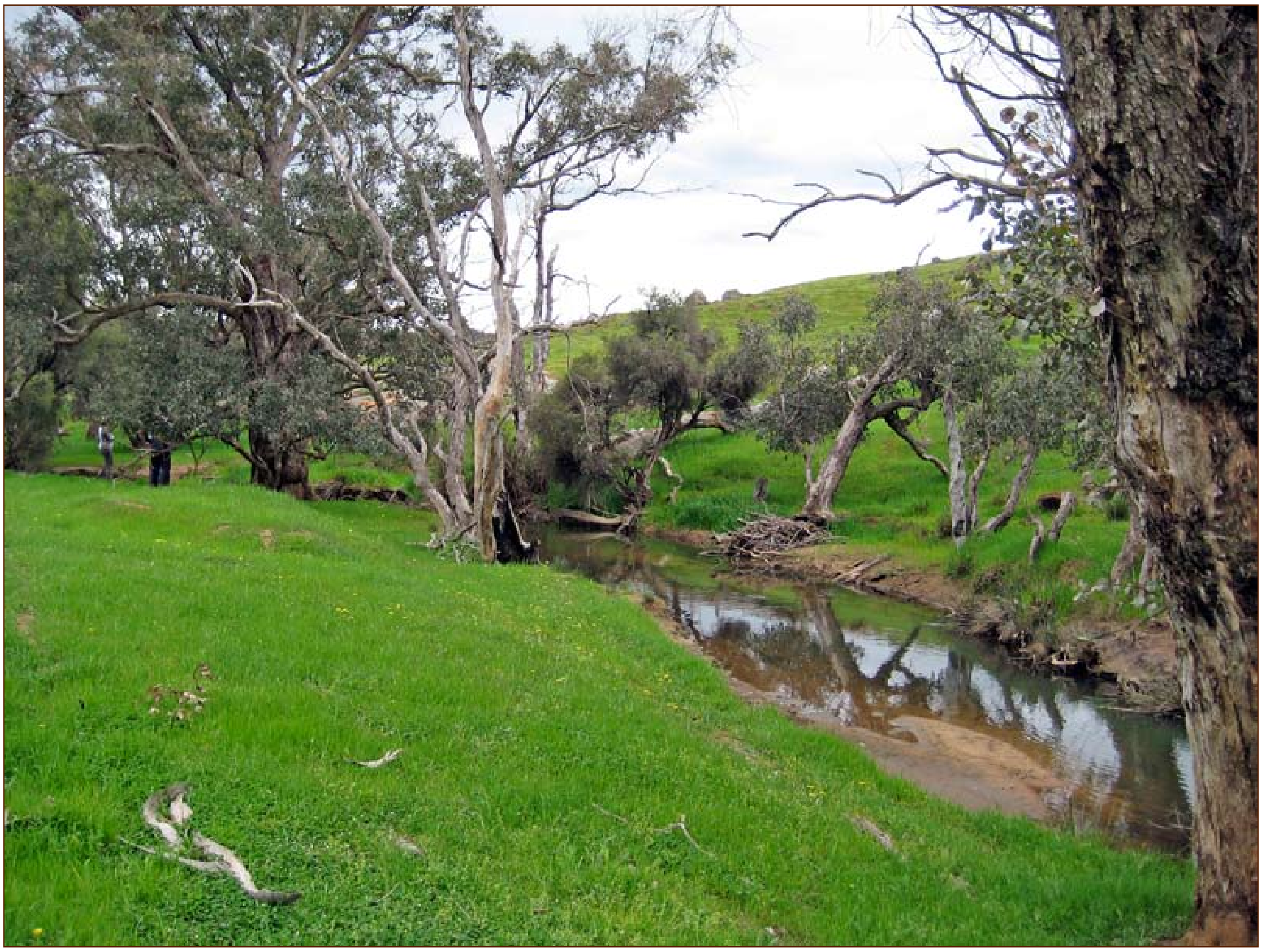


Figure 17 **Permanent stream running through farmland at Quindanning. When soil pH is maintained at target levels off-site impacts are reduced.**

Benefits of liming

Profitability

The profitability of liming will differ according to individual circumstances and many factors need to be taken into account:

Gross margin of the paddock

What are the potential profits from crops which can be grown when pH is not limiting (Figure 18), compared 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 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 and soil type are important. Topsoil pH responds quickly to liming. Surface applied lime usually takes four to seven years to treat acidity in the subsurface layers provided that sufficient lime is applied to raise and maintain the topsoil pH above 5.5. 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.

Figure 18 **Canola crop at Boothendarra. Liming as an integral part of farming practice will maintain crop choice, production and profitability.**

Production benefits

It is not always desirable to see a response to liming because this indicates that production has been lost. 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 8–12 per cent after the application of 1 or 2 t/ha of good quality lime to acidic soils, based on DAFWA data from hundreds of trial-years (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. 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, Figure 19). 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 observed to be increased after liming.

The trial examples on the following pages highlight the long-term benefits of liming.

Table 6 **Average crop grain yield responses to surface-applied lime as the per cent yield change compared to unlimed control plots for DAFWA soil acidity trials**

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

Figure 19 **DAFWA trial site at Holt Rock demonstrates production benefits after liming to recover acidic soil**

Benefits of liming

Long-term large-scale lime trial at Bindi Bindi

This trial was established in 1996 at Bindi Bindi on a sandy gravel soil. Plots 50 x 200 m were treated with surface applications of 1 and 2 t/ha limesand, control plots were unlimed and all plots had three replications.

Wheat

The productivity of wheat was measured in 1996, 1998, 2004 and 2007 (Figure 20). A basic economic analysis was performed using cost of limesand applied 2 t/ha in 1996 at $44/ha (current $75/ha) (Table 7). The cumulative benefit from four years of wheat was $200/ha.

Table 7 **Basic economic analysis of liming on wheat rotations at Bindi Bindi**

Year	Wheat yield t/ha		% yield increase	$/ha benefit
	No lime	2 t/ha Lime		
1996	2.2	2.2	0	$106[1]
1998	1.6	1.8	11	
2004	2.5	3.2	22	
2007	2.6	2.9	10	$107[2]

[1] Using 2005 wheat prices and distributing the cost of the lime over 10 years at 8% interest. Benefits from increased pasture growth not included in analyses.

[2] 2007 prices

Pasture

Pasture biomass was measured in 2005. The biomass was 70 per cent greater in the 2 t/ha lime treatment plot than the unlimed plot.

Soil

After having been above the topsoil target pH for many years, the soil pH for the limed plots (2 t/ha lime in 1996) is now back to the pH levels of 1996 before liming, indicating that the applied lime has been completely used. Where no lime was applied the soil profile continued to acidify (Table 8) and aluminium levels are now toxic (Table 9).

Table 8 **Soil pH response measured in 2007 to lime applied in 1996**

Depth (cm)	Soil pH (ppm)*		
	0 t/ha lime	1 t/ha lime	2 t/ha lime
0–10	4.5	4.8	5.0
10–20	4.0	4.1	4.4
20–30	4.1	4.2	4.5

Table 9 **Average soil aluminium measured in 2007 for plots with lime applied in 1996**

Depth (cm)	Soil aluminium (ppm)*		
	0 t/ha lime	1 t/ha lime	2 t/ha lime
0–10	Not measured—organic matter in topsoil causes misleading results		
10–20	7	4	2
20–30	7	3	2

* Aluminium rule-of-thumb: < 2 ppm Al nontoxic, 2–5 ppm toxic to sensitive species, > 5 ppm toxic to tolerant species.

Figure 20 **Harvesting the long-term large-scale trial established in 1996 at Bindi Bindi**

Long-term farmer trial at Kellerberrin

This trial was established by the farmer in 1991 at Kellerberrin on yellow sandy earth. Lime was surface-applied to plots at 1, 2.5 and 5 t/ha, the control plots were unlimed and all plots had three replicates. All treatments received a further 1 t/ha of surface-applied lime in 2001.

Wheat

Wheat yield in 2008 for the 5 t/ha lime treatment was significantly greater than the 1 or 2.5 t/ha plots which were greater than the unlimed plot (Table 10, Figure 21). The differences are more meaningfully considered as a loss of productivity of between 7 and 17 per cent in the insufficiently or unlimed plots. Treatment differences of at least this magnitude have been commonly observed by the farmer during the life of the trial.

The application of 5 t/ha of lime in one year is unlikely to be the most effective application strategy due to the cost of incurring the expense up front. A more effective strategy would be to apply sufficient lime, in several applications, to treat the soil acidity over a longer period.

Table 10 **Benefit in 2008 of lime applied in 1991**

Lime (t/ha)	Yield (t/ha)	% of max. yield	benefit ($/ha)
0	2.9	83	
1	3.3	93	99
2.5	3.2		
5	3.5	100	174

Soil

Long-term, where enough lime has been applied (the 5 t/ha treatment), the acidic subsurface soil has been ameliorated (Figure 22). To maintain the soil pH profile it is estimated that an additional 2 t/ha lime will be needed over the next 10 years. However, to recover the soil pH profile for the other treatments, a much greater amount of lime (7–10 t/ha) and time (10–20 years) will be needed.

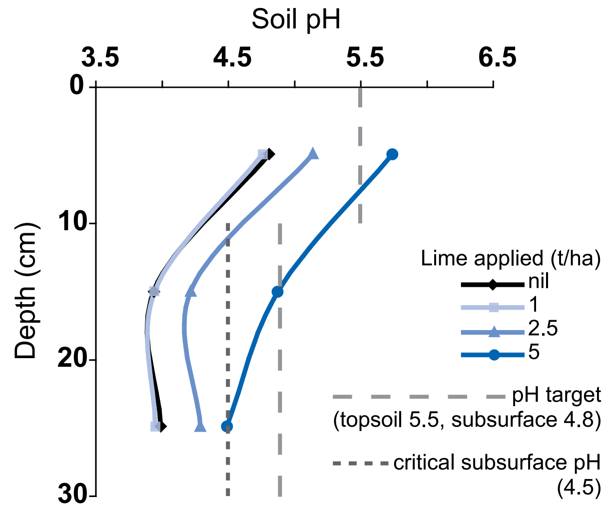


Figure 22 **Soil pH measured 17 years after the initial lime application**

Figure 21 **Kellerberrin trial site. Limed treatment in foreground; control plot has radish weeds**

Pasture lime response—liming on the lines

The tennis courts at Tammin provide a quirky pasture demonstration site (Figures 23 and 24) showing the impact of continuous fertiliser applications and product removal on acidification and the response to the lime used to mark the lines on the old grass tennis courts (Table 11).

Table 11 **The lime used to mark lines on the tennis court at Tammin has reduced soil acidity caused by produce removal (mowing) over the years.**

Sample depth (cm)	Soil pH	
	On lines	Off lines
0–10	4.3	3.9
10–20	4.9	3.6
20–30	5.5	3.8

Figure 23 **Sampling the tennis courts at Tammin**

Figure 24 **The tennis courts at Tammin**

PART 2

Chemistry and biology of soil acidity

pH scale

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

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

Soil pH buffering

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

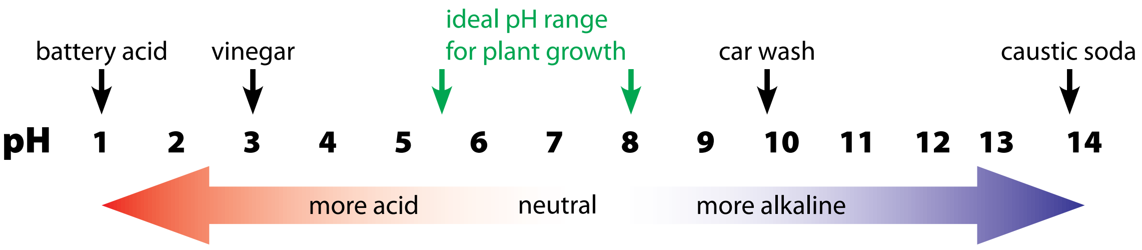


Figure 25 **Examples of where common substances fit on the pH scale**

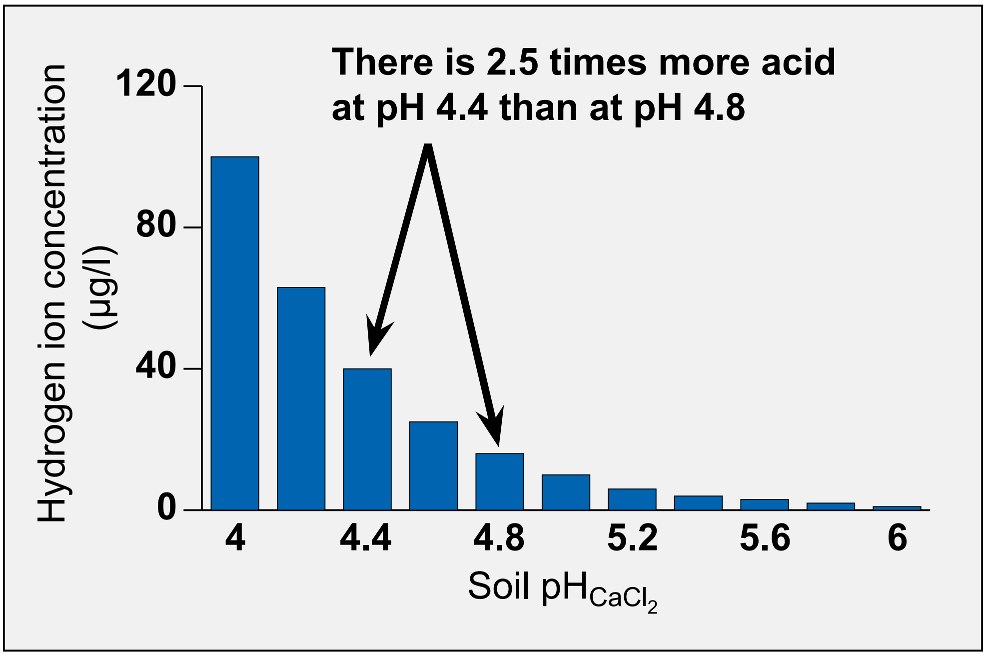


Figure 26 **A small decrease in soil pH from 4.8 to 4.4 results in a 2.5 times increase in acidity because of the logarithmic relationship between pH and hydrogen ion concentration.**

Measurement of pH

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

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

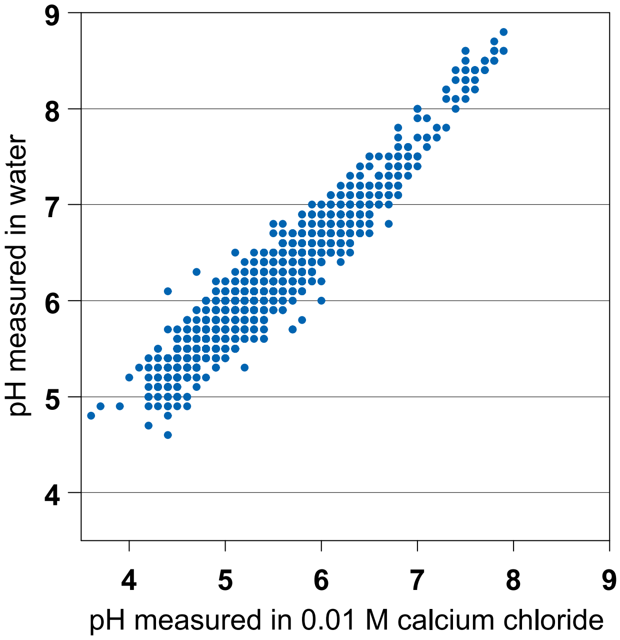


Figure 28 **Comparison between pH measured 1:5 soil:water and pH measured 1:5 soil:0.01 M calcium chloride for WA wheatbelt soils**

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

Effects of soil acidity

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

Aluminium toxicity

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

In most wheatbelt soils, aluminium will reach toxic levels when subsurface pH falls below 4.8. Generally, there is sufficient organic matter in topsoil so that aluminium can remain bound and does not become toxic to plant roots even though it is extractable in laboratory analysis.

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

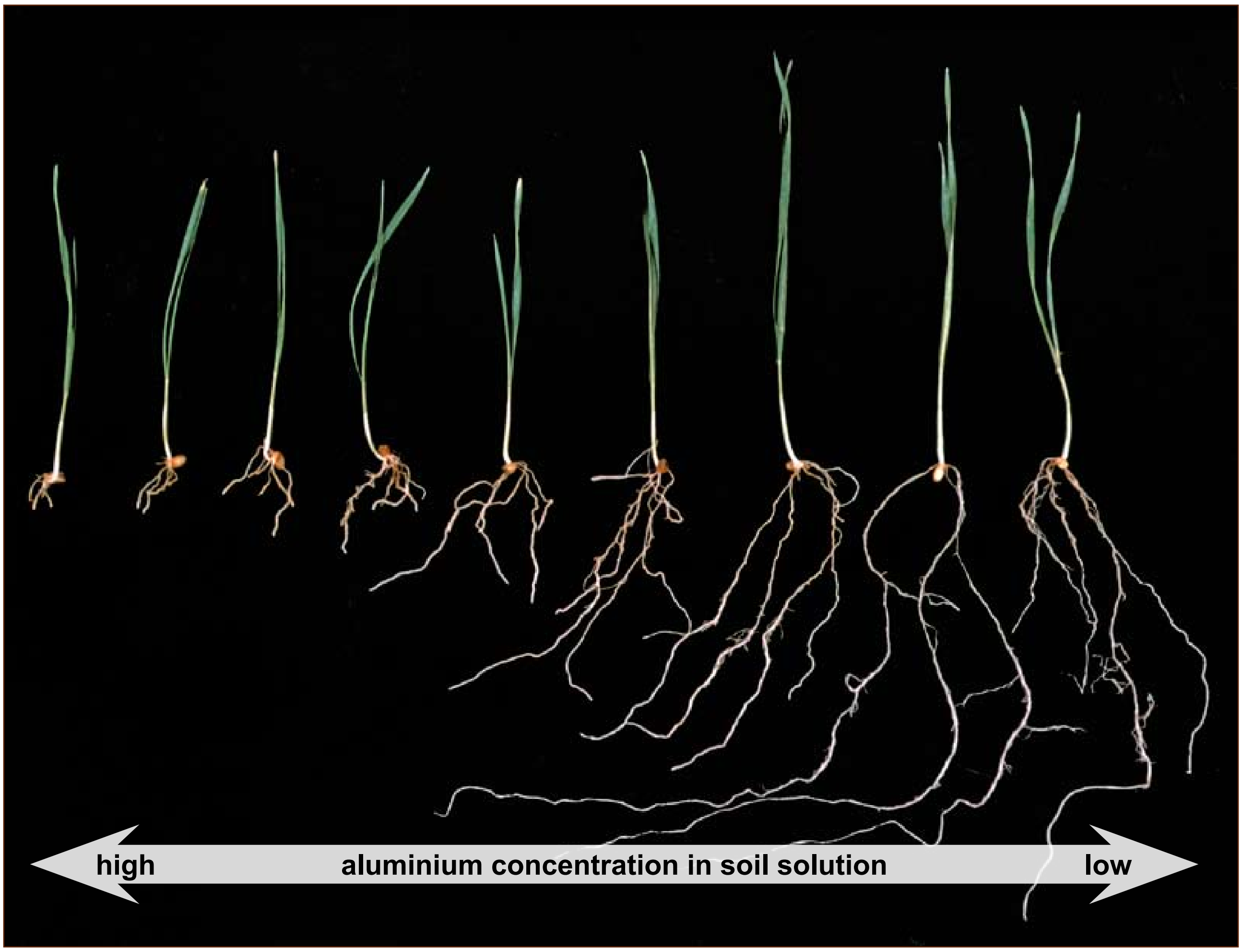


Figure 29 **Wheat seedlings grown in soil with a range of aluminium concentrations. Photo: S Carr**

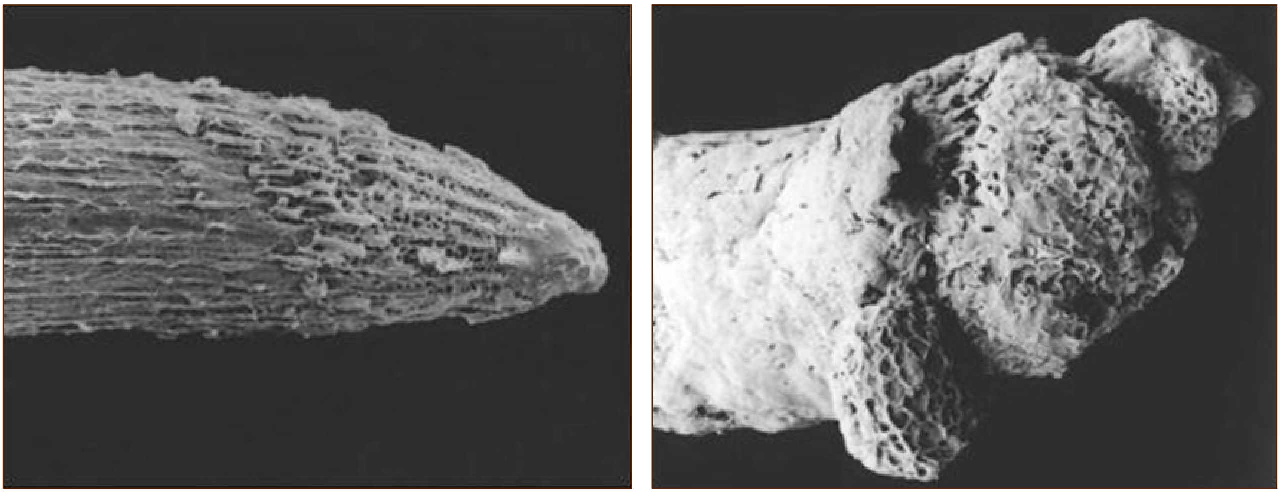


Figure 30 **Healthy root tip (left) compared to a root tip affected by aluminium toxicity (right). Photos: CSIRO**

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

Measurement of soil aluminium

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

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

Nutrient availability

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

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

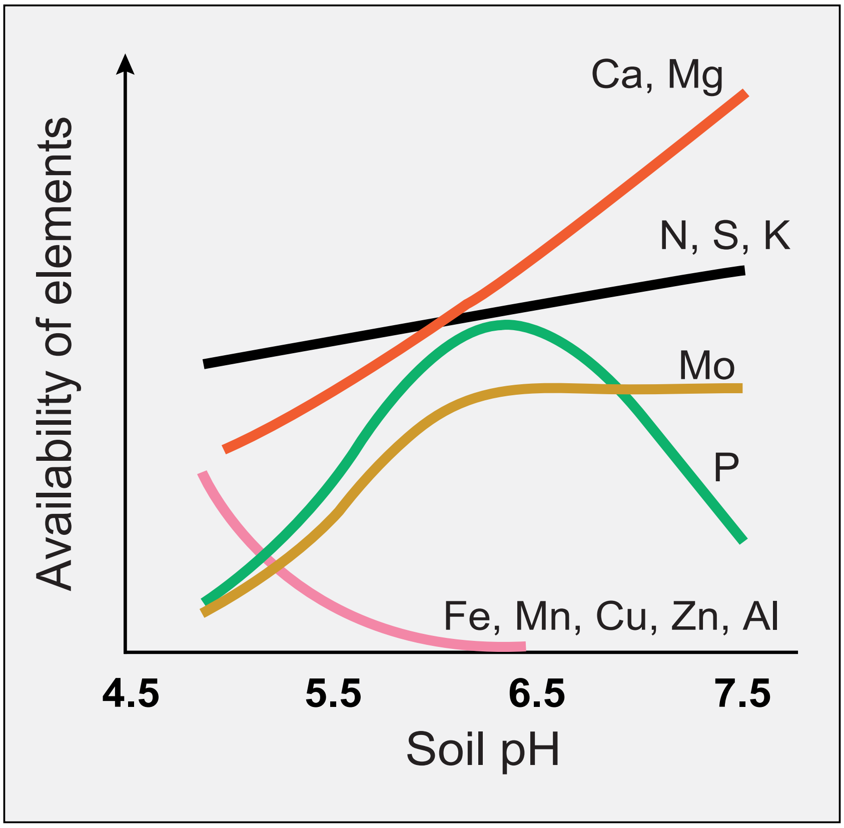


Figure 32 **Relationship between soil pH and nutrient availability. In acidic soils, some nutrients may be insufficiently available for optimal plant growth and aluminium may become toxic.**

Soil microbial activity

Most microbial processes are reduced in acidic soil because growth and reproduction of the soil microbes, primarily bacteria and fungi, are reduced. Breakdown of organic matter and cycling of nutrients is reduced. The rate of mineralisation of nutrients by soil microbes into plant-available forms is slower, potentially limiting plant uptake. Most importantly, legume nodulation can fail. Under favourable conditions, nitrogen-fixing rhizobia bacteria form a symbiosis with crop and pasture legumes in root nodules (Figure 33). In acidic soils, rhizobia bacteria may be unable—or populations too low—to form a functioning symbiosis, resulting in nitrogen deficiency. Species of rhizobia bacteria vary in their tolerance to soil acidity, for example, medic rhizobia are very sensitive and may fail to persist. Grass-dominated pastures can result from the failure of pasture legumes to thrive in acidic soil.

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

Causes of soil acidity

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

Nitrate leaching

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

Ammonium nitrogen from fertiliser or soil organic matter is readily converted to nitrate and hydrogen ions by bacteria in the soil. Different amounts of hydrogen ions are contributed to the soil, depending on the fertiliser. If nitrate is not taken up by plants, it can leach away from the root zone. Nitrate ions are readily leached from most WA agricultural soils because there are more negatively charged surface sites on soil constituents (required to retain the negatively charged nitrate ions) than positively charged surface sites. If nitrate leaches, a positively charged cation is also leached to maintain electrical balance. The cations that leach are usually sodium, potassium or calcium because hydrogen ions are more strongly held by the soil. The result is a net increase in hydrogen ions.

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

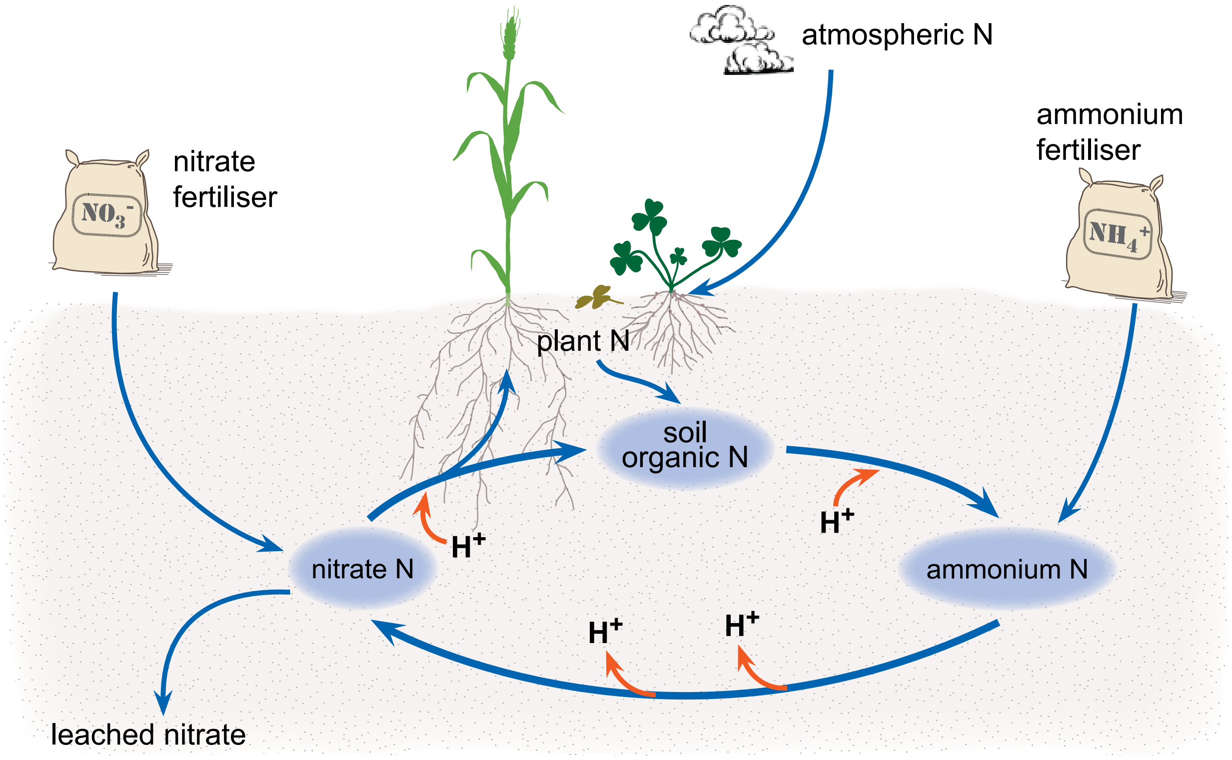


Figure 34 **The main pathways showing the involvement of nitrogen (N) fertilisers in soil acidification**

Export of produce

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

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

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

PART 3

Agricultural lime guide

Lime sources

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

Limesand

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

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

Figure 36 **Limesand mine near Dongara**

Limestone

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

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

Figure 38 **Limestone mine near Myalup**

Dolomitic lime

(usually marketed as dolomite)

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

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

Figure 40 **Dolomitic lime mine near Watheroo**

Other liming products

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

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

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

Lime quality

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

How lime works

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

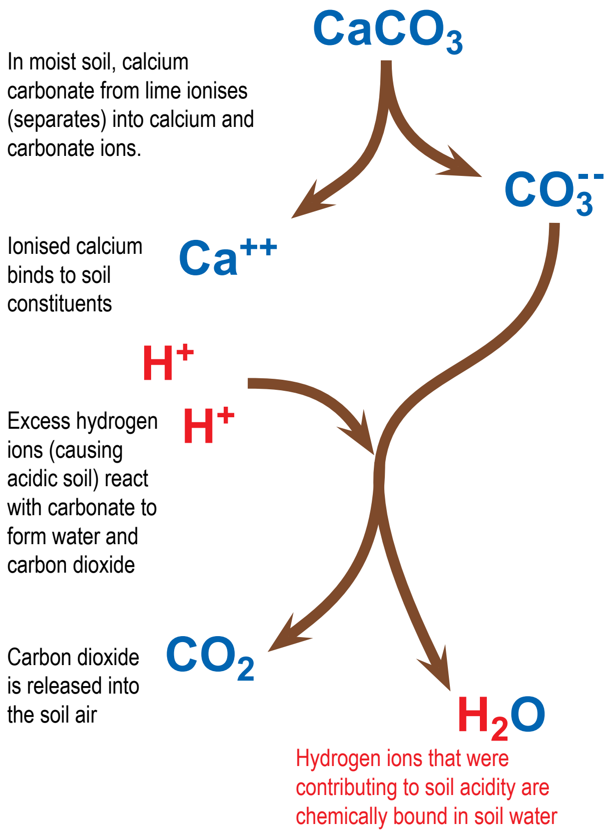


Figure 42 **Simplified representation of how lime reacts in soil to treat acidity. There are more-complicated chemical steps in this pathway, but the end result is that the soil has more calcium ions on the exchange surface, carbon dioxide is released into the soil air and hydrogen ions that were contributing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

Neutralising value

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

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

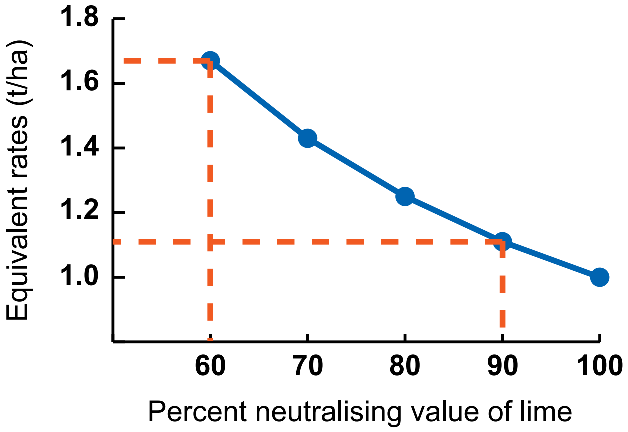


Figure 43 **Lime required to apply the equivalent neutralising capacity for agricultural limes of differing neutralising value**

Particle size

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

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

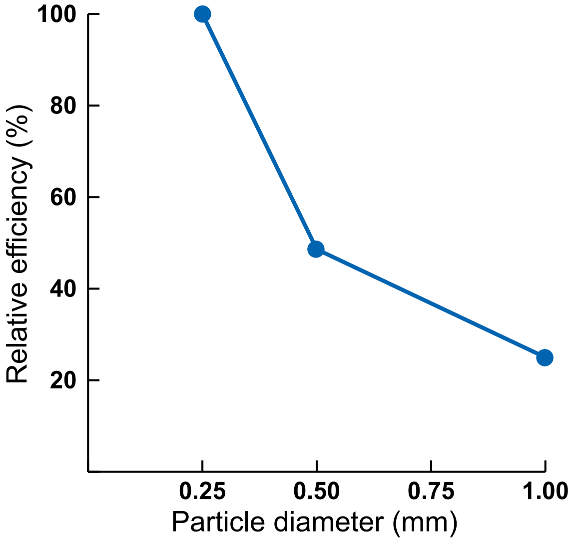


Figure 44 **Relative efficiencies of particles of agricultural lime in changing soil pH for an application rate of 2.5 t/ha (from Cregan et al., 1989)**

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

Comparing limes

When selecting an agricultural lime to treat soil acidity the total cost needs to be considered. The total cost includes the purchase cost at pit, transport cost to paddock and spreading cost; all converted to 100 per cent neutralising value 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 (Figure 46). The lime supplier should provide up-to-date particle size and neutralising value information that will allow calculation of the best value lime.

Lime comparison calculator

A useful tool for calculating and comparing the cost-effectiveness of agricultural limes is the lime comparison calculator on the soilquality.org.au website. To allow comparison of the total cost per hectare for the equivalent of 100 per cent 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.

The neutralising values of larger particle sizes are discounted using the values of Cregan et al. (1989) (Figure 44) to account for the reduced capacity to change soil pH in the short term. The neutralising value of particles under 0.5 mm is not discounted, the neutralising value of 0.5–1 mm particles is discounted by 50 per cent and the neutralising value of particles greater than 1 mm is discounted by 80 per cent.

The calculations performed by the lime comparison calculator (Figure 47) can be calculated by hand (see the worked example, page 38).

Figure 46 **With high neutralising value limes, you can buy and transport less for the same pH change.**

Worked example

1. Calculate the percentage efficiency of the lime

Add (sum) the per cent efficiency (EP) for each particle size.
EP for the particle size = % of lime x neutralising value (NV) x particle size discount factor.

Particle size (mm)	Particle size discount factor	% of lime*	NV*	Per cent efficiency (EP)
0–0.125	1	5	90	(5 ÷ 100) x 90 x 1 = 4.5
0.125–0.25	1	48	90.5	(48 ÷ 100) x 90.5 x 1 = 43.4
0.25–0.5	1	38	94.8	(38 ÷ 100) x 94.8 x 1 = 36.0
0.5–1	0.5	8	72.1	(8 ÷ 100) x 72.1 x 0.5 = 2.9
> 1	0.2	1	62.5	(1 ÷ 100) x 62.5 x 0.2 = 0.1
				SUM = **86.9**

* Current information should always be provided by the lime supplier.

2. Calculate the costs

In this example, the lime costs $10 per tonne and needs to be transported 250 km to the farm. It can be spread for $8 per tonne.

Item	Cost/tonne ($)
lime	10
transport (at 10c/km/t for 250 km)	25
spreading	8
	SUM = **43**

3. Calculate the cost of effective lime on paddock

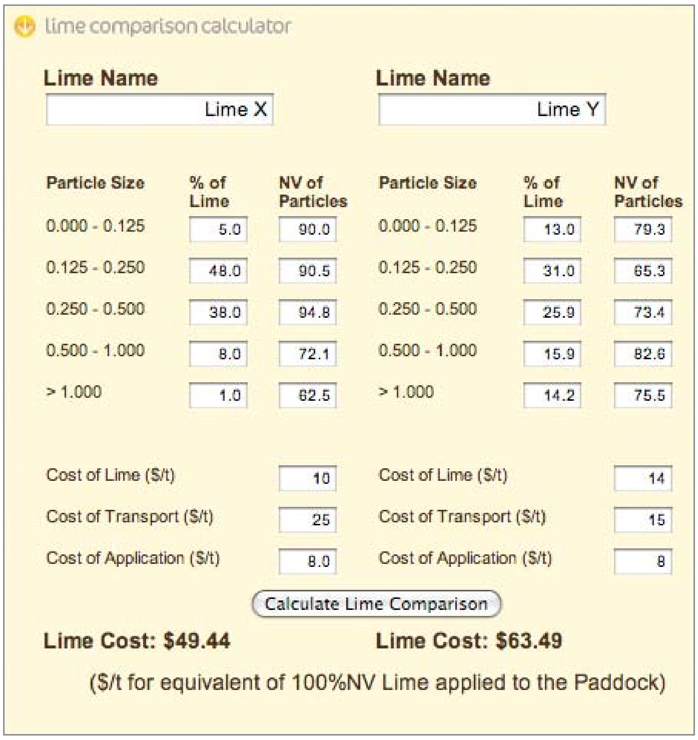
Effective cost = (100 ÷ EP) x costs

For a lime with 100 per cent 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. In this example,

***Effective cost** = (100 ÷ **86.9**) x **43** = $49.48*

Online calculations

The easiest way to compare the cost-effectiveness of limes is to use the online lime comparison calculator on the Soil Quality website, www.soilquality.org.au. Lime suppliers should provide recent product test results detailing the information required for the calculations. Figure 47 shows the above example (lime X) compared to a coarser lime of lower overall neutralising value (lime Y). Even though lime Y is 100 km closer to the farm, it is still more cost-effective to purchase lime X.



lime comparison calculator

Lime Name Lime X

Particle Size	% of Lime	NV of Particles
0.000 - 0.125	5.0	90.0
0.125 - 0.250	48.0	90.5
0.250 - 0.500	38.0	94.8
0.500 - 1.000	8.0	72.1
> 1.000	1.0	62.5

Cost of Lime ($/t) 10
Cost of Transport ($/t) 25
Cost of Application ($/t) 8.0

Lime Name Lime Y

Particle Size	% of Lime	NV of Particles
0.000 - 0.125	13.0	79.3
0.125 - 0.250	31.0	65.3
0.250 - 0.500	25.9	73.4
0.500 - 1.000	15.9	82.6
> 1.000	14.2	75.5

Cost of Lime ($/t) 14
Cost of Transport ($/t) 15
Cost of Application ($/t) 8

Lime Cost: $49.44

Lime Cost: $63.49

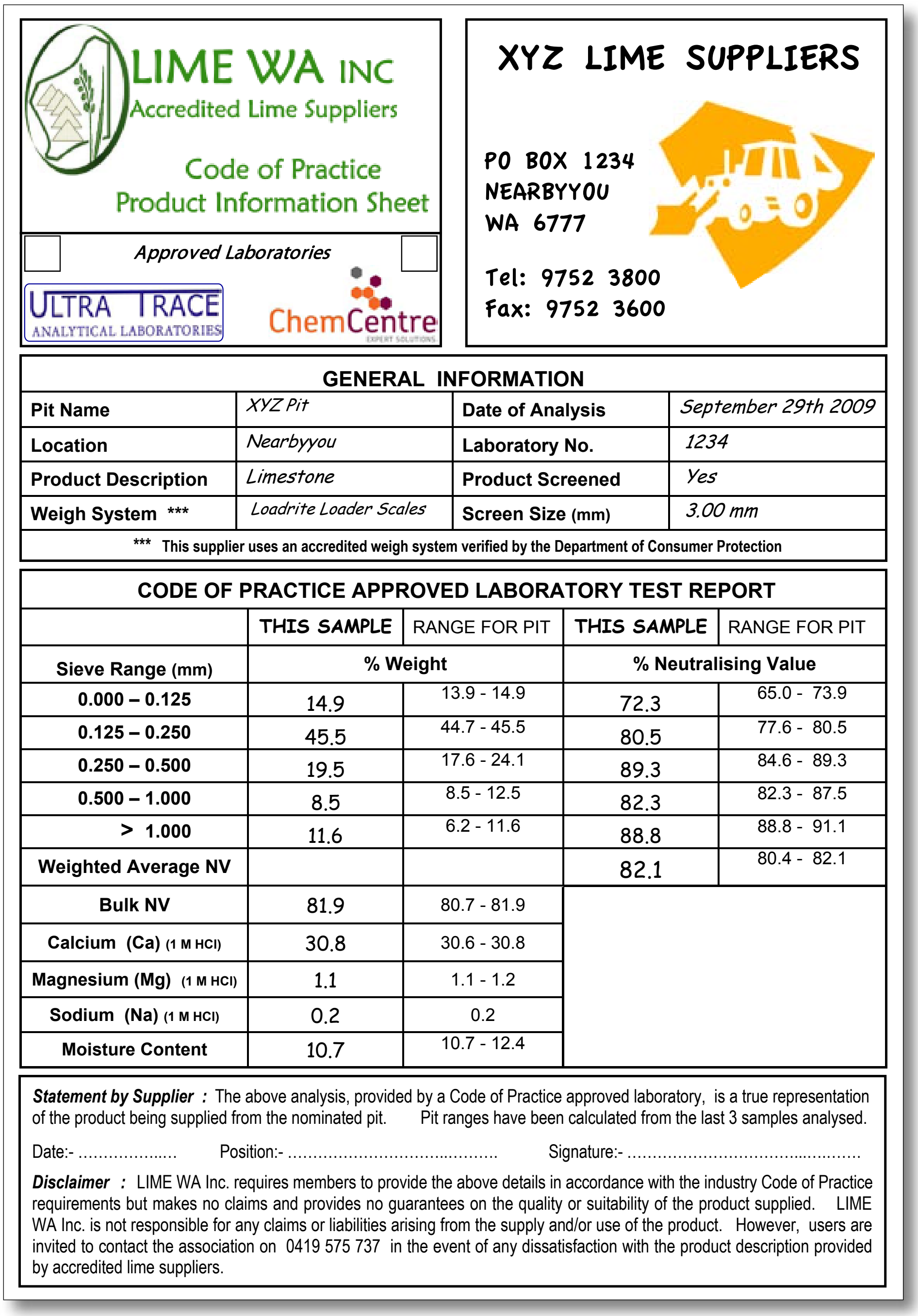
($/t for equivalent of 100%NV Lime applied to the Paddock)

Figure 47 **Limes compared using the online lime comparison calculator at www.soilquality.org.au**

WA lime suppliers

Approximately 40 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. 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 Inc. group of independent lime suppliers and operate under the voluntary 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 (Figure 48) (downloadable from www.limewa.com.au) which can be used with the soilquality.org.au online lime comparison calculator.



LIME WA INC
Accredited Lime Suppliers

Code of Practice
Product Information Sheet

☐ Approved Laboratories ☐

ULTRA TRACE
ANALYTICAL LABORATORIES

ChemCentre

XYZ LIME SUPPLIERS

PO BOX 1234
NEARBYYOU
WA 6777

Tel: 9752 3800
Fax: 9752 3600

GENERAL INFORMATION

Pit Name	*XYZ Pit*	**Date of Analysis**	*September 29th 2009*
Location	*Nearbyyou*	**Laboratory No.**	*1234*
Product Description	*Limestone*	**Product Screened**	*Yes*
Weigh System ***	*Loadrite Loader Scales*	**Screen Size (mm)**	*3.00 mm*

*** This supplier uses an accredited weigh system verified by the Department of Consumer Protection

CODE OF PRACTICE APPROVED LABORATORY TEST REPORT

	THIS SAMPLE	RANGE FOR PIT	THIS SAMPLE	RANGE FOR PIT
Sieve Range (mm)	**% Weight**		**% Neutralising Value**	
0.000 – 0.125	14.9	13.9 - 14.9	72.3	65.0 - 73.9
0.125 – 0.250	45.5	44.7 - 45.5	80.5	77.6 - 80.5
0.250 – 0.500	19.5	17.6 - 24.1	89.3	84.6 - 89.3
0.500 – 1.000	8.5	8.5 - 12.5	82.3	82.3 - 87.5
> 1.000	11.6	6.2 - 11.6	88.8	88.8 - 91.1
Weighted Average NV			82.1	80.4 - 82.1
Bulk NV	81.9	80.7 - 81.9		
Calcium (Ca) (1 M HCl)	30.8	30.6 - 30.8		
Magnesium (Mg) (1 M HCl)	1.1	1.1 - 1.2		
Sodium (Na) (1 M HCl)	0.2	0.2		
Moisture Content	10.7	10.7 - 12.4		

Statement by Supplier : The above analysis, provided by a Code of Practice approved laboratory, is a true representation of the product being supplied from the nominated pit. Pit ranges have been calculated from the last 3 samples analysed.

Date:- .... Position:- .... Signature:- ....

Disclaimer : LIME WA Inc. requires members to provide the above details in accordance with the industry Code of Practice requirements but makes no claims and provides no guarantees on the quality or suitability of the product supplied. LIME WA Inc. is not responsible for any claims or liabilities arising from the supply and/or use of the product. However, users are invited to contact the association on 0419 575 737 in the event of any dissatisfaction with the product description provided by accredited lime suppliers.

Figure 48 **Product information sheets can be downloaded from the Lime WA Inc. website (www.limewa.com.au).**

PART 4

Common questions

Which lime should I buy?

The best lime is the cheapest per unit of neutralising value purchased, delivered and spread on farm. Sometimes it is better value for money to transport a higher quality product further. Simply follow these steps:

- Soil test at 0–10, 10–20 and 20–30 cm to determine where, and at what rate, you need to lime.
- Obtain product information sheets from suppliers (download from www.limewa.com.au).
- Gather costs for lime, cartage and spreading.
- Use the lime comparison calculator at www.soilquality.org.au to compare the total cost of effective neutralising value delivered and spread on 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 www.limewa.com.au). The product information sheet openly displays the range of test results for the lime source, indicating the consistency of the product.

Is limestone better than limesand?

No—the capacity to change soil pH is governed by neutralising value. 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.

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 6–8 m (depending on wind conditions) to get good coverage of fine particles (Figure 49).

Figure 49 **Testing agricultural lime spreading. Photo: D York**

Lime sources

What is the difference between agricultural lime and other lime?

Limesand, limestone and dolomitic lime (dolomite) are the most common agricultural limes. They are natural, mined products comprised mostly of calcium carbonate with some magnesium carbonate (Figure 50).

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 is unstable and will revert to calcium carbonate if stored exposed to air.

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 www.limewa.com.au.

Figure 50 **Mining limesand—limesand, limestone and dolomitic lime are natural mined products.**

Why do I need to lime? What is the effect of soil acidity?

All forms of productive agriculture remove alkalinity from the farm, which leaves the soil more acidic (low pH). The effect of soil acidity is to change the availability of water and nutrients, mainly through reduction of root growth caused by aluminium toxicity at low pH in the subsurface soil. Low soil pH can also reduce the chemical availability of nutrients, making it harder for plants to access them. Adequate applications of agricultural lime can maintain soil pH or recover acidic soil to target levels, preventing production loss due to soil acidity (Figure 51).

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

Liming to maintain the topsoil pH above 5.5 will treat ongoing acidification and allow sufficient alkalinity to move down and treat subsurface acidification. If the subsurface soil is already acid, maintaining topsoil pH above 5.5 will prevent further subsurface acidification. However, more frequent applications and/or higher rates of lime will be required to recover the subsurface pH to above 4.8.

Can I burn stubble after liming?

The temperatures reached during stubble burning will not affect lime. After burning, there is less protection from wind erosion and the risk of losing applied lime is greater if it hasn’t been incorporated.

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?

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 quickly and once the acidity has been neutralised, the lime dissolves only very slowly. This remaining lime will continue to treat the ongoing acidification which results from farming. Applying high rates of lime where some of the micro-nutrients including manganese, zinc and copper are marginal, may induce deficiencies that can be overcome by the application of appropriate fertiliser as solid or foliar spray.

Figure 51 **Lucerne persists on the limed profile (right) at Konnongorring.**

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 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.

How long after liming should I soil sample?

To observe changes in soil pH as a result of lime application, monitoring should be done approximately three years after application (Figure 52).

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.

If I have a paddock at pH 4.8 and another at 5.3, which gets priority?

This choice is complicated and it all depends on the subsurface pH. You need to test the soil at 10–20 and 20–30 cm as well as the topsoil. It is wise to protect the better-performing paddocks if subsurface pH is limiting production to maintain farm income and subsequently treat other paddocks. Remember that soil acidification will continue in paddocks under agriculture and more lime will be required to recover soil pH.

Figure 52 **Soil profile stained with universal indicator at Hyden—the orange colour indicates an acidic layer at about 10–20 cm. Soil profiles that have an acidic layer will usually be corrected quicker following liming than a profile which is acidic to depth.**

Where is it best to apply lime within the paddock?

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 blanket application over the whole paddock. For example, if some areas of a paddock required 2 t/ha and some required 3 t/ha, a strategy could be to apply 2 t/ha to the whole paddock, recheck pH in three years and apply 1 t/ha to the areas which required 3 t/ha.

Why is 2 t/ha often recommended now? This seems more than previously.

Over the last 15 years (since the old 1 t/ha in 10 years recommendation) the soil profile has continued to acidify because, generally, insufficient lime has been applied and production has increased due to improvements in agricultural practices; therefore, more lime is now required to treat the more acidic soils. Liming recommendations should always take into account the pH of the soil profile, soil type, rainfall and farming practice.

At what pH should we start putting out lime? What is an acceptable low pH?

It is best to maintain pH at or above 5.5 in the topsoil and 4.8 in the subsurface. If the topsoil pH 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. 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 practice and production will be lost.

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. 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. If compaction is also a production constraint, applying lime to the surface prior to deep-ripping will be beneficial (Figure 53).

Figure 53 **A trial at Maya showed the value of surface applying lime prior to deep-ripping**

What is the value of applying lime in spring? Is it the best time?

Lime can be applied at any time it fits into the farming schedule, particularly with tramline farming systems (Figure 54). Spring liming of pastures is beneficial to a following cropping rotation as there is time for the lime to start neutralising acidity, particularly if there is summer rainfall.

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 1 t/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.

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 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.

Figure 54 **Tramline farming at Buntine. Tramline farming makes it easy to apply lime whenever it fits into the farming schedule**

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