2001

Western Australia soil acidity research and development update 2001: time to lime

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Western Australia
Soil Acidity
Research & Development

TimetoLime
Agriculture
WESTERN AUSTRALIA
FOREWORD

This book for 2001 again summarises the work being carried out by staff of The Integrated Soil Acidity Research, Development and Extension projects in Western Australia. These projects are based at Agriculture Western Australia, The University of Western Australia and CSIRO.

Several articles in this book are an indication that the current round of funding for this work is drawing to a close in June 2002. The articles reflect our increasing understanding of not only the effects of soil acidity but also the time required for current practices of surface applied lime to ameliorate acidity in both the surface and subsurface.

The seasonal conditions of 1999 and 2000 were particularly difficult for some growers and put pressure on cash flow and the ability of some to address medium to long term investments such as managing soil acidity through the application of liming materials. It was therefore very pleasing to us that although the amount of lime applied in 1999/2000 was down from the record of 650,000 tonnes in 1998/1999 to about 576,000 tonnes the number of growers using lime actually increased slightly.

We have tried to provide in this book a summary of our knowledge that has been developed over several years and I would encourage you to contact the authors if you require further information.

Finally, I would like to thank all the members of the Soil Acidity Team for their commitment, professionalism and support during the last year.

Mr Chris Gazey
Project Manager
The Western Australia Soil Acidity Research Development and Extension Project wishes to thank the following organisations for their support:
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LIMING AND RELIMING ENHANCE BARLEY YIELD ON ACIDIC SOIL

C. Tang and Z. Rengel

Soil Science and Plant Nutrition, University of Western Australia

KEY MESSAGES

- Barley yields increase as a result of ameliorating topsoil and subsurface acidity.
- The benefits of liming last at least 16 years after initial application at 2.5 t /ha.
- Reliming after 15 years further increases barley yield.
- Surface liming at relatively high rates can ameliorate subsurface acidity in the long term.

INTRODUCTION

Soil acidity with high levels of toxic Aluminium (Al) is a major limiting factor in most cereal producing soils in the WA wheatbelt. Liming is a common practice to ameliorate topsoil acidity in the relatively short term, and can ameliorate subsurface acidity in the longer term. Soil acidity will impair root growth of sensitive crops, reduce water and nutrient uptake, and subsequently decrease the yield.

Barley is a short-season crop and has been promoted for late sowing opportunities. However, barley is particularly sensitive to soil acidity and managing this problem is essential for a successful barley crop on acidic soils. This article reports on a field trial that examined the effect of liming and reliming on the yield of barley grown in an acid soil.

METHODS

A field trial was conducted on a sand over gravel at Wongan Hills (Peter Sadler, Leahurst Farms - 15 km east of Wongan Hills). The trial used large strips of land (25 m x 1 km) limed at 0 and 2.5 t/ha in 1984. In 1999 1.5 t/ha of lime was applied to portions of the previously unlimed and limed strips. Therefore, four soil acidity profiles were created. The barley crop was sown in ten replicates over each of the soil profiles. The trial was sown on 17 June 2000, and was managed by the farmer. Soil samples were taken at five depths in 10-cm intervals from individual plots in August. Plants were sampled in the booting stage (7 September) and at maturity.
RESULTS

As expected, four distinct soil pH profiles were found in 2000 (Fig. 1). Where no lime was applied in either 1984 or 1999, the pH in the topsoil was about 4.7, decreased to 4.1 in 10-30 cm and then increased with depth. Applying lime at 1.5 t/ha on the unlimed strip increased pH by 0.9 units in the topsoil but hardly affected the pH in 10-30 cm, indicating that the amount of lime movement below 10 cm was small. Where 2.5 t/ha of lime were applied in 1984, pH in 0-20 cm was about 5.0, increased with depth and reached 6.0 at the layer of 40-50 cm.

Applying lime on the limed strip increased the pH by 1.3 units in the topsoil and by 0.3 units at 10-20 cm, indicating that some of the lime applied in 1999 moved down to the 10-20 cm layer when the surface pH was only slightly acidic, and that reliming may accelerate lime movement down the profile. The pH difference below 30 cm between unlimed treatments and those limed in 1999 presumably resulted from soil heterogeneity at the site.

In the limed strip, concentration of extractable Al was below 1.5 mg/kg in the soil profile. By contrast, in the unlimed strip Al concentrations increased with depth, reached a maximum of 17 mg/kg in the 20-30 cm and then decreased with depth (Fig. 1). Application of lime in 1999 did not significantly affect the Al concentrations in the soil profile. Irrespective of lime treatment and soil depth, there was a very close relationship between pH and Al concentration; decreasing soil pH exponentially increased Al concentration with a critical pH of 4.6 (Fig. 2).

![Graph showing soil pH and Al concentration](image-url)

Figure 1. Soil pH and exchangeable Al concentrations in soil profiles of control (no liming), and after liming at 2.5 t/ha in 1984, liming at 1.5 t/ha in 1999, and liming in 1984 plus in 1999 (84+99) on the field trial site at Wongan Hills. Soils were sampled in August, 2000. Horizontal bars indicate the standard error.
Application of lime in 1984 and/or 1999 markedly increased barley shoot biomass at booting, number of heads and grain size (Table 1). Compared to the no lime control, liming increased shoot biomass by 55-71 per cent, and head number by 30-35 per cent. Seed weight was significantly increased only in the treatment combining applications of lime in 1984 and again in 1999.

Table 1. Shoot biomass at booting, number of heads and grain size of a barley crop grown with various lime treatments on the field trial site at Wongan Hills in the 2000 season. Numbers in parentheses represent percentages.

<table>
<thead>
<tr>
<th>Lime treatments</th>
<th>Shoot biomass (t/ha)</th>
<th>Head number (million/ha)</th>
<th>Grain weight (g/1000 seeds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Control (no lime)</td>
<td>2.44 (100)</td>
<td>3.18 (100)</td>
<td>40.0 (100)</td>
</tr>
<tr>
<td>2) Liming at 1.5 t/ha in 1999</td>
<td>4.18 (171)</td>
<td>4.32 (136)</td>
<td>41.9 (105)</td>
</tr>
<tr>
<td>3) Liming at 2.5 t/ha in 1984</td>
<td>3.82 (157)</td>
<td>4.12 (130)</td>
<td>39.9 (100)</td>
</tr>
<tr>
<td>4) Liming in 1984 and 1999</td>
<td>3.78 (155)</td>
<td>4.22 (133)</td>
<td>43.9 (110)</td>
</tr>
</tbody>
</table>

Grain yield increased in all limed treatments compared with the no lime control (Fig. 3). Among the lime treatments, liming in 1984 plus reliming in 1999 gave the best seed yield, followed by liming in 1999, and liming in 1984, indicating that reliming is necessary for the optimal barley yield.
Figure 3. Grain yield of barley grown with no lime control, liming in 1999 (L99), liming in 1984 (L84), and liming in 1984 and reliming in 1999 (L84+99). Values above bars are relative yields.

Multiple regression analysis was performed to predict crop performance under acidity stress. Total biomass and grain yield (kg/ha) of the barley crop at maturity correlated positively with pH of top 10 cm soil (0.01 CaCl₂) and negatively with Al concentration (mg/kg) in 30-40 and 40-50 cm.

Acknowledgements

Thanks to David Gartner, staff of the Wongan Hills Research Support Unit, Bart McGann, Chris Gazey, Mark Whitten, Eugene Diatloff and Daniel Murphy for field assistance and discussion, and Grains Research and Development Corporation (GRDC) for financial support. Special thanks to Mr Peter Sadler for the use of his land.
CANOLA - MORE RESPONSES TO LIME

Chris Gazey and Paul Carmody

Agriculture Western Australia, Centre for Cropping Systems, Northam

KEY MESSAGE

Although canola is known to be highly responsive to lime, further testing has shown yield responses are more likely on soils with pH < 4.5 and where lime has been applied two to four years prior to the canola. Responses to lime can be anticipated for up to nine years after application.

In 2001, plant canola on paddocks where lime has previously been applied (two to four years).

INTRODUCTION

For the past decade, research in WA into canola responses to lime has been about as exciting as it can get. This paper reviews this work and reports on more recent results in 1999 and 2000. It forms part of a larger project for studying lime in the system, which uses both small plot trials and large-scale demonstration sites to illustrate the benefits of lime. Lime is a good investment. By correcting soil acidity it encourages better root growth and exploration.

Growers are pushing the limits of canola’s tolerance to low soil pH as production packages become more refined. Canola is more sensitive to low pH than crops such as wheat and lupins. However, reasonable crops of 1.0 to 1.2 t/ha are being grown on soil with very low pH (e.g. 4.3 in 0–10 cm and 3.9 in the 10–20 cm, measured in Calcium Chloride). Increasing soil acidity is a long-term problem and with rising costs, canola is proving to be one of those crops that will realise returns much sooner from the dollars invested in lime. But how much is this worth?

METHODS

During 1999 and 2000 three old lime trials were sown with canola; one at Varley (Bruce Hill’s property), one at Mullewa (Desmond’s property) and a third at Buntine (Kim Diamond’s property). All paddocks have been a part of a wheat – lupin - canola rotation.

In 1999, on a large site at Buntine, canola was sown across three treatments of lime applied in 1996. At Mullewa last year large plots of Karoo canola were sown across 1996 treatments of nil, 1 and 2 tonnes of lime. In 2000, the farmer sowed the 1994 trial, at the Lake Varley site, as part of the paddock and then individual plots were harvested using a small plot harvester.
Trials were assessed for grain weight using a weigh trailer or a plot harvester depending on the site. Soil pH_{CaCl_2} measurements have been made at all sites every year since each trial was established.

RESULTS

Yield increases in canola have been observed in most trials with lime (Table 1), regardless of the amount of time since the lime had been applied. This was despite the fact that the subsurface pH was still quite acid. Early growth responses were observed and these persisted during the season for all trials except the lime trial established in 1996 at Varley (96LG7), which also gave significant grain increases.

Table 1. Canola grain yields (t/ha) for various lime trials over last three seasons.

<table>
<thead>
<tr>
<th>Lime Rate (t/ha)</th>
<th>Trial (year lime applied)</th>
<th>Canola 1996</th>
<th>Canola 2000</th>
<th>Canola 1999</th>
<th>Canola 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.29 a</td>
<td>1.85 a</td>
<td>0.74 a</td>
<td>1.32 a</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>1.42 b</td>
<td>1.92 ab</td>
<td>N/T</td>
<td>N/T</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.55 c</td>
<td>1.92 ab</td>
<td>0.99 b</td>
<td>1.46 b</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>1.69 d</td>
<td>2.01 bc</td>
<td>0.86ab</td>
<td>1.60 c</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>1.67 d</td>
<td>2.11 c</td>
<td>N/T</td>
<td>N/T</td>
<td></td>
</tr>
<tr>
<td>l.s.d</td>
<td></td>
<td>0.15</td>
<td>0.18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Numbers in the same column with the same letter are not significantly different (p<0.05).

N/T: No treatment at this level of lime was made at this site.

* Additional lime treatments of dolomite and G-Lime were also used in trial 96LG7. Dolomite was less effective than G-Lime, which was less effective than limesand. However, all amendments increased canola grain yield above the unlimed treatment. Neutralizing Values of amendments: Limesand 97% NV, dolomite 67% NV, G lime 100% NV. Rates were adjusted to account for the lower NV of this product to allow for a fair comparison.

The pH results for two of the trials are presented below (Table 2a, b). In the Narrogin trial (96NA3) there was an increase in soil pH below the zone of incorporation (0–10 cm). There was also a significant increase in the pH in the 10-20 cm layer at Varley, seven years after the lime was applied and there was a similar increase at Buntine, four years after the lime was applied.
Table 2a. pH measured in 0.01M CaCl$_2$ in 1999 for 96TS3, (lime spread in 1996).

<table>
<thead>
<tr>
<th>Depth</th>
<th>0 (t/ha lime)</th>
<th>1 (t/ha lime)</th>
<th>2 (t/ha lime)</th>
<th>Stats (l.s.d) 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10 cm</td>
<td>4.39</td>
<td>5.64</td>
<td>6.48</td>
<td>0.50</td>
</tr>
<tr>
<td>10-20 cm</td>
<td>4.11</td>
<td>4.50</td>
<td>4.74</td>
<td>0.53</td>
</tr>
<tr>
<td>20-30 cm</td>
<td>4.16</td>
<td>4.57</td>
<td>4.43</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 2b. pH measured in 0.01M CaCl$_2$ in 2000 for 94LG18, (t/ha lime spread in 1994).

<table>
<thead>
<tr>
<th>Depth</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 10 cm</td>
<td>4.52</td>
<td>5.17</td>
<td>5.21</td>
</tr>
<tr>
<td>10 – 20 cm</td>
<td>4.17</td>
<td>4.44</td>
<td>4.60</td>
</tr>
<tr>
<td>20 – 30 cm</td>
<td>4.68</td>
<td>4.74</td>
<td>4.78</td>
</tr>
</tbody>
</table>

**DISCUSSION OF RESULTS**

The above data is not a summary of all the lime trials in which canola was planted. The most recent applications of lime (1998) did not show a response in 2000 and this is possibly due to the dry conditions not allowing the neutralising effect of the lime on the surface to occur.

Amazingly, the Lake Grace site where lime was applied in 1994 continues to show the greatest responses of all the sites. Here the pH ranges from 4.75 on the surface to 4.43 at depth whereas at Mullewa it ranges from 5.28 to 4.25 at depth and no significant response was detected there in 2000. The Narrogin site has a more consistent pH down the profile around 4.70 similar range and gave an immediate response the year after application.

Purely from a canola point of view, the investment in lime at Varley has been highly profitable. At this site increased canola responses in 2000 has virtually paid for the cost of applying over one tonne of lime ($45/ha). Some simple costs for lime are summarised in Table 3.

Table 3, Cost of lime in the three major regions of the wheatbelt.

<table>
<thead>
<tr>
<th>Lime price</th>
<th>Southern</th>
<th>Central</th>
<th>Northern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight cost</td>
<td>$34.00</td>
<td>$20.00</td>
<td>$9.00</td>
</tr>
<tr>
<td>Spreading costs</td>
<td>$8.00</td>
<td>$8.00</td>
<td>$8.00</td>
</tr>
<tr>
<td>Total lime cost per tonne</td>
<td>$47.30</td>
<td>$33.30</td>
<td>$22.30</td>
</tr>
</tbody>
</table>

When evaluating lime, it is important to consider the particle size, its neutralizing value, and the grade of lime and, therefore, this table is a simplification of the true cost of lime in the different regions of WA.

No benefit can be attributed to oil bonus. Where oil contents have been done no significant differences could be detected between treatments. In future, a closer look
at the effect of lime on diseases in canola, like blackleg or damp off diseases, could be more important (Arshad et.al. 1997).

The longer the lime has been applied, the better the investment looks for canola responses. According to a commercial operator\(^1\), although none of their sites that were sown to canola gave a response to lime in 2000, one site at Wongan Hills where lime was applied 13 years ago gave a significant response in 2000.

A more detailed economic analysis of the benefits of lime in the system will be presented at the 2001 AGWEST Crop Updates.

**CONCLUSION**

On average, canola responses range from 0.1 to 0.26 tonnes per hectare two to nine years after application of 1 tonne of lime per hectare. In the year canola is grown, this amounts to $30 to $75 alone, but the benefit carries across all crops in the system. Only a few trials have had oil contents measured and there appears to be no relationship between oil content and the rate of application of lime at this stage. This work has further consolidated the importance of applying lime to canola on soils, which tend towards more acidity (<4.5 pH).

While previous work suggested that, in some cases, canola responded immediately to lime, this is dependant on the seasonal conditions and the baseline acidity at the beginning.

Where the pH is low, there are clear benefits to liming paddocks being sown to canola. Cash flows in 2000/2001 are tight which means only the very “hottest” of paddocks should be considered for liming in 2001 and seeding them to seradella or pasture. Canola should only be grown on those paddocks that have had lime applied two to four years previously to ensure a benefit this year. Growers should not only be looking at these potential short term responses, but also understand that lime has a long residual value and reapplication is usually only required once every five to seven years. The other obvious benefit of managing acidity is the wider choice of crops available to be grown, including barley and acid sensitive wheat varieties, allowing for more profitable and sustainable rotations.

**References**

\(^1\) Personal communication, Lorelle Lightfoot, AgLime Australia, WA

Time to Lime, Demonstration results 1996 to 1999, AGWEST, Mis pub. No. 16/00


ALUMINIUM-TOLERANT WHEAT HAS HIGHER YIELD AND IMPROVES WATER USE UNDER SUBSURFACE acidity

C Tang¹, D Abrecht² and Z Rengel¹

1. Soil Science and Plant Nutrition, University of Western Australia
2. Agriculture Western Australia, Merredin

KEY MESSAGES

• Aluminium-tolerant wheat yields higher than aluminium-sensitive wheat when grown in soil with subsurface acidity.
• Aluminium-tolerant wheat produces more roots and grows deeper than aluminium-sensitive wheat in acidic subsoil.
• Aluminium-tolerant wheat utilises more water from acidic subsoil than aluminium-sensitive wheat.

INTRODUCTION

Subsurface acidity limits cereal production in vast areas of the WA wheatbelt. Subsoil acidity will impair root growth of sensitive crops and hence reduce water and nutrient uptake, particularly in the latter part of the season. Both acidity and water deficits will induce yield loss. Crop cultivars differ in their susceptibility to aluminium (Al) toxicity in acid soils. Selection of tolerant cultivars in combination with surface liming may provide the best solution to the subsoil acidity problem.

This article reports on the growth, water use and yield of aluminium-tolerant and aluminium-sensitive wheat varieties in response to subsoil acidity and water supply.

METHODS

A field trial was conducted at the Dryland Research Institute, Merredin. The site had soil pH about 4.3, Al level 5 mg/kg and electrical conductivity 60 µS/cm below 10 cm (Fig. 1).

Figure 1. Soil pH, exchangeable Al concentration and electrical conductivity in soil profiles of the field trial site at Merredin. Horizontal bars indicate S.E.
The trial was set up in a split-plot design with seven water treatments as main plots and two genotypes as subplots. The water treatments were: natural rainfall, weekly, fortnightly and monthly irrigation of 0.3 or 0.6 of the pan evaporation (pans). It was expected that the weekly irrigation treatments would mainly moisten the topsoil, whereas the monthly irrigation treatments would moisten the whole soil profile.

The two wheat genotypes used were near-isogenic Al-tolerant (ET8) and Al-sensitive (ES8) wheat lines. The comparison of yields between these two genotypes would provide an estimate of the yield benefits from growing Al-tolerant wheat on acidic soils under various watering regimes. Neutron moisture probe access tubes were installed before sowing for measurements of soil moisture profiles during the growing season. The trial was sown on 29th June and irrigation started seven weeks after sowing.

RESULTS

Shoot biomass was measured fortnightly. ET8 produced more shoot biomass than ES8 from 76 days under monthly irrigation, and from 104 days under natural rain and weekly irrigation. At maturity, ET8 produced 51 per cent higher yield than ES8 under natural rain (Fig. 2).

Under irrigation, ET8 produced up to 26 per cent higher yield than ES8 but the yield difference was greater in monthly irrigation treatments (Fig. 2). ET8 also had 1000-grain weight, on average, 4 per cent greater than ES8.

Figure 2. Grain yield of ET8 and ES8 grown with subsurface acidity under various water regimes. Values above the ET8 bars are the % yield increase compared with ES8.

Figure 3. Root length density at booting of ET8 and ES8 grown in soil with subsurface acidity under various water regimes. Bars are LSD values at \( p=0.05 \).
While both genotypes had similar root length density in the topsoil, root length density in the 10-40 cm layer was 20-50 per cent higher in ET8 than ES8 (Fig. 3).

Water use from soil profiles during 16 August–15 October were significantly affected by wheat genotypes. Under natural rain, soil moisture decreased faster under ET8 than under ES8 in soil layers between 10 and 90 cm. Differences in the decrease of moisture content in soil profiles under ET8 and ES8 were even greater in the irrigated treatments.

For example, in the monthly irrigation at 0.3 pans, moisture content decreased by 0.5-1.5 per cent more under ET8 than ES8 in layers between 30 and 110 cm. In the monthly irrigation at 0.6 pans, moisture content in soil profiles decreased by 1 per cent more under ET8 than ES8.

Under irrigation, the decrease of moisture content was not found below 70 cm for ES8 and 110-130 cm for ET8 (Fig. 4). The results also suggest that ET8 produced more roots, and grew deeper than ES8.

**Figure 4.** Absolute changes in soil moisture content under ET8 and ES8 grown with subsurface acidity with various irrigation treatments. Bars are LSD values at $p=0.05$.

**Acknowledgements**

Thanks to Greg Bunker for management of the trial, David Tennant and Ross Thompson for installation of neutron moisture access tubes and helpful discussion, and staff at DRI and UWA for field assistance. The project was financially supported by the Grains Research and Development Corporation (GRDC).
LIME MOVEMENT FIELD TRIALS: FINE LIME MORE EFFECTIVE FOR AT LEAST TWO YEARS

Mark Whitten¹, Mike O’Connell² and Andrew Rate¹
¹ Soil Science and Plant Nutrition, University of Western Australia
² Agriculture Western Australia, Albany

KEY MESSAGE

• The efficiency of lime increases as the particle size decreases. By grinding limesand to about 95 per cent < 0.09 mm the increase in pH at 0-10 cm after two years was the same as with double the amount of unprocessed limesand of particle sizes 95 per cent 0.09-0.5 mm.

• Changes in subsurface pH at 10-20 cm and 20-30 cm after two years were positively correlated with surface pH (0-10 cm) and therefore increased more the higher the lime rate and the finer the lime.

• Barley yield in 2000 was positively correlated with soil pH in the surface and the subsurface. Barley gross margins with 2.5 t/ha of fine lime were $50 /ha higher than the unlimed treatment, and cover the majority of the cost of lime applied in 1998 (assuming $145 /t farm gate).

• These results highlight the importance of always using lime of high quality. In addition, the grinding of limesand on a commercial scale warrants further investigation. Initial investigations suggest that the benefits of using finely ground lime (lower rates, lower transport and spreading costs) may outweigh the costs of grinding, especially for farmers who have to transport lime over long distances.

BACKGROUND

The inverse relationship between lime particle size and effectiveness for managing soil acidity has been well documented in the scientific literature for almost a century, and probably understood at a practical level for much longer.

For WA limes with similar neutralising value but diverse origin and mineralogy, particle size has been shown to be the most important property controlling the rate at which lime will dissolve in controlled laboratory conditions (1999 Western Australia Soil Acidity Update). Preliminary results from field trials established at Wongan Hills in 1998 indicate that finely grinding a widely used limesand resulted in significantly greater pH increases one year after application (2000 Western Australia Soil Acidity Update).

The abundance of limesand in WA has set a defacto standard for particle size, which would be considered coarse elsewhere in Australia or internationally. Crushed
limestones and dolomites in WA often contain a significant proportion of material coarser than limesand.

Most of the reserves of limesand and limestone are located near the coast, hence the cost of transporting either type of lime to much of the WA wheatbelt can exceed its purchase cost. It is, therefore, worth investigating whether the additional costs of processing, to make finer and more effective agricultural lime than is currently generally available in WA, could be offset by lower transport costs.

AIMS
The aims of the field trials at Wongan Hills are to compare the effects of lime particle size (limesand unprocessed or finely ground), tillage (no-till vs incorporation) and lime application rates on the downward movement of surface applied lime. The pH data is presented here two years after liming and the yield of barley in the 3rd season. The cost effectiveness of grinding limesand is also assessed.

METHODS
Three application rates of lime were used at each of two trials (0, 2 or 4 tonnes per hectare (t/ha) at one site on a duplex soil, and 0, 2.5 or 5 t/ha at the other site on a gradational soil). Both trials are in the Gabby Quoi Quoi valley, south of Wongan Hills. Half of the trial plots received unprocessed limesand and the other half received limesand, which had been finely ground by ball-milling (See Figure 1).

To examine tillage effects lime was incorporated into the top 10 cm of half of each plot using a scarifier, with the remainder being uncultivated (no-till); crops in both treatments are seeded with no-till implements.

RESULTS
Efficiency at increasing surface pH
Reducing the particle size of the limesand increased its effectiveness at raising soil pH one and two years after application (See Figure 2). Compared with the unprocessed limesand at the same application rate, finely ground limesand was more efficient by 22-29 per cent on the duplex soil and 37-44 per cent on the gradational soil at increasing surface soil pH (0-10 cm) over the 1998-2000 period.

At each site, the increases in surface pH with the finely ground limesand at the lower rates were approximately the same as with the unprocessed limesand at double the application rate. This does not necessarily mean that less of the fine lime would be required in the long term, although farmers in NSW have needed to re-lime earlier where coarse lime had been applied (Nicoll 2001).

The trials at Wongan Hills indicates that responses and benefits commence earlier with the finer lime, but they would need to continue for a total of at least ten years to determine the long term effects of lime particle size on the soil pH profile and productivity. So far there has been no effect of tillage on surface or subsurface pH.
Figure 1. Particle size distributions of limesand which was unprocessed (95% 0.09-0.5 mm and approximately 80% < 0.355 mm) or finely ground (97%< 0.09 mm and approximately 80% < 0.045 mm).

**Changes in subsurface pH**

There are early indications on the gradational soil that both lime rate and particle size have influenced lime movement, probably because of their effect on surface soil pH.

Two years after liming, the changes in the subsurface pH of the gradational soil (10-20 cm and 20-30 cm depth) were positively correlated with the surface soil pH (0-10 cm), and occurred against a background of decreasing pH since 1998 where no lime was applied. Although the effects of lime rate and particle size were significant, the changes in subsurface soil pH are small and these results remain provisional until confirmed by future measurements.

Figure 2. The effect of lime rate and particle size on pH at 0-10 cm a duplex soil and a gradational soil 2 years after applying unprocessed or finely ground limesand at rates of 2 or 4 t/ha (duplex soil) and 2.5 or 5 t/ha (gradational soil). Error bar is LSD (p<0.05).
Yields

Barley grain yield in 2000 on the gradational soil was positively correlated with both the surface pH (0-10 cm) and subsurface pH (any depth from 20–30 cm to 50-60 cm). The yield increase was about 0.15 t/ha per unit increase in pH from 4.3 to 6.8 at 0-10 cm, and about 0.75 t/ha per unit increase in pH from about 4 to 5 at a depth 20-30 cm, indicating that both surface and subsurface acidity can affect acid sensitive crops such as barley.

Yields were greatest with the finer lime at each rate, increasing from 1.44 t/ha in the control to 1.79 t/ha with finely ground limesand at 2.5 t/ha and to 1.96 t/ha with the same lime at 5 t/ha, representing gains of 24 per cent and 36 per cent. These yield increases translate into gross margins of approximately $50 /ha and $75 /ha higher for the 2.5 and 5 t/ha treatments, respectively, assuming a farm gate price of $145 per tonne.

Using conservative assumptions about future yield response, a payback period of four years for the 2.5 t/ha treatment is anticipated. In most situations, applying lime at 5 t/ha is not recommended. High costs mean that the anticipated payback period is considerably longer. In addition, higher rates mean that the lime budget will not cover as many hectares, and there can be nutritional problems, which may require additional applications of trace elements. (Note: Grain was harvested on the gradational soil only because of water and salt stress on the duplex soil. Yields were 10 per cent lower with no-till but this was not due to lime.)

Implications for growers and advisers

Currently there is little, if any, grinding of limesand on a commercial scale in WA. Some crushed limestone is produced, but not to the fineness used in this study. Therefore, in the short term, farmers applying lime must choose from the current range of products.

The results of this study highlight the importance of using good quality lime. Surveys of lime deposits show that there are large differences in quality between pits. So it is worth taking a little time to find out the quality of the limes available. A fine product with high neutralising value should be preferred, subject to cost and handling difficulties. (Lime of finer grade than WA limesands or limestones is used routinely elsewhere in agriculture in Australia and internationally, indicating that handling problems can be solved).

In the longer term, some lime suppliers may offer grinding of limesand or limestones crushed more finely than are presently available. The benefits of such a service would be that lime could be applied at a lower rate, leading to a reduced transport bill and greater field efficiency when spreading. These benefits must be weighed up against the additional cost of grinding and possible difficulties of storing and spreading a finer product. The following table provides an example of how normal limesand might be compared with a ground product of about 85 per cent physical effectiveness (i.e. not as fine as the finely ground limesand in the Wongan Hills field trials). Grinding limesand to this standard may cost less than crushing quarried limestone.
A slightly higher cost of $6 /t at the pit has been assumed (i.e. no extra transport), although this number is subject to review. The example also assumes that normal limesand would be applied at 1.5 t/ha, and that 0.9 t/ha of the ground product would be equally effective (the unprocessed limesand had a physical effectiveness of 50 per cent compared with the finely ground limesand in this study). As well, it assumes that the finer lime could be spread with the same equipment and that the lower application rate would cost less to spread.

Table 1. Example comparing the cost of using normal limesand and finely ground product.

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Normal limesand</th>
<th>Ground limesand</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Raw product ($ / t)</td>
<td>7.00</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>2. Grinding cost ($ / t)</td>
<td>0.00</td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td>3. Recovery</td>
<td>100%</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td>4. Cost of lime at pit ($ / t)</td>
<td>7.00</td>
<td>13.68</td>
<td>Add row 1 &amp; 2, then divide total by row 3</td>
</tr>
<tr>
<td>5. Transport to farm ($ / t)</td>
<td>15.00</td>
<td>15.00</td>
<td></td>
</tr>
<tr>
<td>6. Cost of lime delivered to farm ($ / t)</td>
<td>22.00</td>
<td>28.68</td>
<td>Add row 4 &amp; 5</td>
</tr>
<tr>
<td>7. Application rate (t / ha)</td>
<td>1.50</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>8. Spreading cost ($ / ha)</td>
<td>11.20</td>
<td>8.50</td>
<td></td>
</tr>
<tr>
<td>Total cost ($ / ha)</td>
<td>44.20</td>
<td>34.32</td>
<td>Multiply row 6 by row 7, then add row 8</td>
</tr>
</tbody>
</table>

In this example the total cost of liming with the finely ground product works out about $10 /ha less than with the unprocessed limesand. If transport costs were higher, then the cost saving would be greater. This means that use of finely ground limesand could be most attractive for farmers who are a long way from lime deposits, as they would be able to cart less lime and save significantly on their total transport bill. Alternatively, the cost savings could allow the lime budget to go further by treating a greater area.

CONCLUSIONS

It has been shown that decreasing the particle size of lime increases its efficiency at raising soil pH at 0-10 cm for at least two years after liming. Increases in subsurface pH (10-20 cm and 20-30 cm), and yield of barley (which is acid sensitive) were positively correlated with pH at 0-10 cm. These gains occurred with a reduction in lime particle size from about 95 per cent <0.5 mm to about 95 per cent <0.09 mm.

Most agricultural limes in WA contain only a small proportion of particles <0.09 mm and may also contain a significant proportion >0.5 mm. Such limes are therefore not as efficient as they would be if more finely ground. Ideally, the trials should run for a total of at least ten years to determine the long-term effects of lime particle size on the soil pH profile and productivity.
The practical implications of these findings are twofold.

Firstly, in the short term growers should always aim to use fine lime with high neutralising value, subject to consideration of cost and handling issues. There are large differences in lime quality, and it is worth looking around for a good product.

Secondly, in the longer term lime suppliers may choose to offer finer lime products, for example by grinding limesand or by additional refining of crushed limestones. Depending on costs, use of a finely ground product is likely to be worthwhile for some growers especially those who have to transport lime a long distance. This would allow significant cost savings on the lime budget, or alternatively, allow the lime budget to treat a larger area.

Further reading

RECOVERING FROM DROUGHT AND FROST - WHAT NOW FOR LIMING PROGRAMS?

Mike O'Connell
Agriculture Western Australia, Albany

KEY MESSAGES

• A run of poor seasons means that many farmers will approach the next few years with defensive management strategies. Liming programs will inevitably come under review.

• Decisions about whether to apply lime require an understanding of the economic implications of liming. These implications are outlined in this article.

• Liming programs must be reviewed on a case-by-case basis. For some growers it will be necessary to defer liming. Others might continue with a small liming program, while those in a position of strength are well placed to enhance the future productive capacity of their land.

• Regardless of short-term decisions about liming, in the long-term liming of acid soils will be an integral part of farming systems. Farmers can ill-afford to allow acidity to run its course unchecked.

BACKGROUND

Following several poor seasons, many farmers are now in recovery mode. For these farmers the next two or three years will be focussed on rebuilding their businesses to a position of strength. In order to achieve this, many will have put the following types of strategies in place:

• Focussing on areas of the farm that generate the most profit. This can include winding back on input levels where the gains from those inputs are likely to be small, and perhaps not cropping poor performing paddocks;

• Being flexible and prepared to "play the season", making the most of every opportunity;

• Working with an appropriate planning horizon. Clearly farmers must be mindful of the long-term implications of their decisions. However, if this year is "make or break" then the planning horizon will be focussed on the short-term;

• Focussing on those enterprises that are known and can produce well. Now is probably not a good time to swing into new or high-risk enterprises.
With such defensive management strategies in place it is timely that growers review their liming programs. In order to respond appropriately it is important that the economic implications of liming are understood, which can be summarised as follows:

- Costs of liming acid soils (at 1 t/ha) are typically in the order of $30 - 60/ha, with the differences being driven mainly by purchase, transport, and spreading costs. These are up front costs that compete directly with other inputs for working capital;

- Benefits (increased yields) vary from site to site depending on severity of acidity, seasonal conditions and acid tolerance of the crop or pasture. Yield increases in the first year are common, but not guaranteed. Expect yield increases to commence within two to four and last for ten plus years;

- Growers should budget on a payback period of four to five years. Faster payback does happen, but to budget on it would be unwise;

- Minor adjustments to fertiliser applications may be required on limed soils, especially where nutrient levels are naturally low or have been run down. This is because liming can alter the soil chemistry and shift nutrient status from marginal to deficient, particularly with manganese on lupins. As a result it might be necessary to spend a little more on fertilisers.

In summary, lime is a medium-long term investment that has an anticipated payback of several years and long lasting benefits. How farmers use this information to adjust their liming program over the next few years will depend on their situation and preferences. The following suggestions will hopefully help in the decision process.

**What now for liming?**

For farmers in a “make or break” situation the decision is fairly straightforward. Don’t lime. The priority for these farmers is to maximise short-term profits to build up the business. Every dollar of available working capital must be spent so that it receives maximum return in the current season, subject to risk considerations. Liming is unlikely to meet this criterion. In some cases the overdraft available won't be sufficient to afford liming after other costs are accounted for anyway.

Then there will be those farmers that have businesses with the underlying strength to continue, but where the last few years have exposed weaknesses that call for some form of restructuring. Again, prioritisation is the name of the game. If the farmer has been liming acid soils already, then it may be feasible to continue with liming as part of the program. However, it might be necessary to reduce the amount of lime spread, as high levels of expenditure could threaten short-term viability.

Lastly, there will be farmers who are in a strong position financially as a result of good management and / or kinder seasons. These producers will no doubt be mindful that an important part of preparing for adverse seasons - which will inevitably happen again - is to manage wisely when times are good. To this end, these producers will be
capitalising on the opportunities that the current downturn offers for strengthening their farm businesses. They are in an ideal situation to address their soil acidity problems on the farm, and will reap considerable future benefits from doing so.

**Liming in the future**

Regardless of short-term decisions about liming, it is vital to keep acid soils management in mind, and ultimately in farming practices. Soil acidity is a problem that threatens as much as two thirds of the agricultural region in Western Australia. Left unmanaged it will continue to worsen as higher and higher levels of production are obtained from the land.

This analysis clearly shows that liming represents an attractive investment over the medium to long term. In addition, local research and development has demonstrated that liming can be successfully incorporated into farming systems. So while it will be appropriate for some farmers to defer their liming programs for the short term, over the longer term it will continue to be "Time to Lime".

**Further reading**

The following article provides an excellent summary of "recovery principles":


LIME USE IN WESTERN AUSTRALIA

Amanda Miller
State Development Officer – Soil Acidity,
Agriculture Western Australia, Lake Grace

BACKGROUND
Agricultural lime use in Western Australia has increased by a staggering 495,851 tonnes between 1994/95 and 1998/99. Given that very few farmers are liming areas for a second time, this means that almost 2.1 million hectares of acid soils have been treated since 1994/95.

In 2000, the grainbelt of Western Australia, which is the primary focus of this project, suffered another serious climatic event on the back of a series of challenging seasons.

1998 Widespread and serious frost event that halved grain production in some areas.

1999 Serious frost events that had a reasonable impact on grain production and an extended and wet harvest that caused significant grain quality downgrades.

2000 One in one hundred year flood event in January, a very late start to the season (Mid June) then the start of a drought that saw grain yields fall by 50 or 60 per cent in some shires.

The result was a decrease in lime use due to economic and physical pressures on the farming business. The impact of these events is expected to continue for another two to three years as farm financial stability returns.

2001 INDUSTRY UPDATE

Lime Use
In 2000 there were 43 companies selling lime products (limesand, limestone, dolomite, cement/lime kiln dust, other) from 50 commercial lime pit operations. The Australian Bureau of Statistics reported 575,980 tonnes of lime were used in 1999/2000. The aim of the project is to reach a target of 750,000 tonnes annually by 2002, although the actual requirement annually is 1 to 1.5 million tonnes.

It is understood lime use fell in 1999/2000 in response to tighter whole of farm budgets.
Area Treated

As lime use changes so does the amount of area treated. Over the last five years lime application rates have remained steady at approximately 1.1 tonnes per hectare. As lime use fell 77,371 tonnes between the peak in 1998/99 and 1999/2000 it was expected that the area treated with lime would also decrease. In this case the treatment area fell by 84,008 hectares.
Farmer Adoption Rate

The most encouraging fact from the 1999/2000 ABS data was the number of farmers that were applying lime. In a year that saw lime use fall by just under twelve per cent, the number of farmers applying lime actually increased by 43 farmers or 1.5 per cent (refer figure 3).

Figure 3: Farmer adoption rate of agricultural lime in Western Australia. (Statistics provided by the Australian Bureau of Statistics)

Although this increase may seem small, the significance is very large. For instance, if more farmers are applying lime in years of poor farm economics, this indicates the growing importance farmers are placing on the use of lime in a sustainable farming system.

Effectively, more farmers were applying a little less lime on a per farm basis i.e. 1998/99 an average of 223 hectares per farm versus 194 hectares per farm in 1999/2000. The significant fact was that growers did not stop applying lime; they simply decreased the area they treated, signifying the growing importance of addressing soil acidity as part of the whole farm enterprise.

Industry Value

The agricultural lime industry in Western Australia has grown and is valued at between $15 and $20 million annually, based on a conservative estimate. The industry now provides a multitude of additional jobs in the extraction, transport and spreading industries. Truck movements (i.e. transport of lime to a location and return) alone are between 16 and 19 thousand per year; travelling in the order of 3 million kilometres annually to achieve the task.
Figure 4: Estimated value of the Agricultural Lime Industry in Western Australia.

Figure 5: Estimated agricultural lime industry truck movements in Western Australia.
Outlook for 2002

The agricultural lime use outlook for 2002 remains positive despite the decline in lime use in the 1999/2000 liming season. The Australian Bureau of Statistics will be changing its reference point in the 2000/01 Agricultural Census from a March 30th collection to a June 30th collection.

The consequence on the industry is two fold. Firstly, it will more accurately reflect the WA liming season that runs from November to June. Secondly, it will mean a delay in the availability of preliminary estimates from October to January, hence the market intelligence will be “out of step” with the season. The net impact on data quality is expected to be minimal.

Acknowledgements

The extension work is supported by growers, Agriculture Western Australia, the Australian Bureau of Statistics, the Natural Heritage Trust and the Grains Research and Development Corporation (GRDC).

Keywords

Lime use, Agricultural Lime Industry, Western Australia.
SOIL ACIDITY IN THE CENTRAL REGION 2000

Sally-Anne Penny
Dryland Research Institute, Merredin

BACKGROUND

Soil acidity in the central wheatbelt is now becoming a major management issue for many farmers. This is because of the regions naturally acidic soils, and farming history, which encompasses a high product removal, use of nitrogenous fertilisers, and legume based rotations.

Adoption of soil acidity technology is being embraced, however, it has not been as rapid as in the Northern agricultural region due to seasonal issues and transport costs.

TRIALS

The lime demonstrations and trials established in 1996 at Tammin, Southern Brook, Darkan, Narrogin, and Wickepin, and those established in 1997 at Narrogin, and in 1998 at Beverley were monitored in 2000. No significant yield data was obtained due to the paddocks being either in pasture, or the dry start to the season meant crops were not put in or failed.

Two trials that were established in 1994 at Carrabin were relimed in 2000 at 1.5t/ha and were pasture manipulated ready for cropping in 2001.

A demonstration results book is now available which goes through the results of all the demonstrations comprehensively from 1996-1999.

LIME SOURCES / USE

The only active lime pit located in the central/eastern wheatbelt is a dolomite pit at Westonia. All other lime products are sourced from outside the area. Due to the high cost involved in getting lime to the central and eastern wheatbelt, compared to other areas, farmers need to be more aware of lime quality issues in order to find the best product.

Lime use in the central region has only slightly surpassed what was spread in 1999. According to the Australian Bureau of Statistics over 110,000t of lime was used in the central region.

2001 IN FOCUS

All of the trial sites will continue to be monitored in 2001. A deep banding lime site will be established at Bodallin and the reliming trials at Carrabin will be in crop. We expect lime usage to be the same or less this year due to the low commodity prices, and the average to below average 2000 season.
SOIL ACIDITY IN THE NORTHERN REGION

Leanne Clune and David Gartner
Agriculture Western Australia, Wongan Hills
Agriculture Western Australia, Moora

BACKGROUND
Soil acidity in the Northern region has become a major management issue and has lead to the whole of the region embracing soil acidity technology more quickly than the Central and South East regions. There are probably three reasons for this observation.

1. Large areas of soils classified as high risk i.e. sandy soils with low buffering capacity, good rainfall, considerable use of high analysis nitrogen fertilisers and consistent average to above average yields.

2. Good quality lime is available in relatively close proximity, when compared to the Central and South East.

3. A focus of the 'Time to Lime' campaign and active lime company marketing in the area north of the Great Eastern Highway. This work has aimed to increase general awareness and to foster a high uptake of the systems application of soil acidity technology by consultants and company agronomists.

TRIALS
Eleven major lime demonstration trials were established in 1996 at Northampton, Maya (2), Kalannie, Three Springs, Mullewa, Bindi Bindi, Watheroo, Dandaragan and Moora (2) to look at different levels of lime applied. Some of the trials are looking at different lime sources i.e. chalk lime, dolomite, limestone and limesand products. The 'Western Australia Soil Acidity Demonstration Site Results 1996 - 1999' is a comprehensive report on all of the lime demonstration sites. This booklet is available from the Agriculture Western Australia Merredin Office.

Three deep banding trials have been established this year at Perenjori, Kalannie and Wongan Hills. These trials are applying limesand and dolomite at varying rates between 10 – 25 cm below the surface, with a view to reducing the subsurface pH and Aluminium levels. Early indications from the Perenjori trial conducted in 2000 have shown an increase in pH and a decrease in Aluminium levels. It should be noted this work is still in its infancy and will continue to be monitored and developed in the future.

Chris Gazey and Dave Gartner are also establishing a residual chemical trial at the Wongan Hill Research Station. This will investigate the interaction between residual chemical and high pH, as there has been some indication that soils with a high pH will carry over more residual chemical than soils with a lower pH.
There is also ongoing work in Dandaragan looking at the establishment of perennial pastures on acid soils. This work is being done in conjunction with the pasture group from Agriculture Western Australia.

Trials this year at Jurien Bay and Wongan Hills are investigating the use of a fertiliser and water solution to form a crust on lime heaps and therefore prevent them from blowing. The most successful result was using a mixture of five parts water to one part ammonium based fertiliser. The mixture was successful in stabilising the lime heap for up to six to eight weeks after application. Approximately 300 litres of water and 60kg of fertiliser were required to cover a 40t limesand heap. Investigations into the stabilisation of lime piles will continue this year.

All of these trial sites will continue to be monitored in 2001.

**LIME PITS AND LIME USAGE**

There are approximately 19 lime suppliers in the Northern region. According to the Australian Bureau of Statistics, approximately 151,000 hectares of agricultural land was limed last year.

**2001 IN FOCUS**

Landholders in the Northern region are continuing to apply lime this year, however lime usage is expected to be lower than last year. This is due largely to the impact of the year 2000 dry season. More landholders are opting to spend money on soil testing this year to determine the pH of their soils and therefore work out what remedial action will be required in the future.

**Acknowledgements**

The extension work is supported by growers through the Natural Heritage Trust, the Grains Research and Development Corporation (GRDC) and the Cereals Program and the Pulse and Oilseeds Program of Agriculture Western Australia.

**Key Words**

Northern region, lime use, lime quality
SOIL ACIDITY IN THE SOUTH COAST REGION

Patricia Hill
Development Officer (AGWEST)
Ravensthorpe Community Agricultural Centre

PRESENT

The region has approximately 587,000 hectares of farmland with about 75 per cent (or 440,250 hectares) predicted to be acidic and at risk of further soil acidification. The complement is made up of alkaline clays and loams surrounding the Ravensthorpe town site, ancient lake deposits and coastal limestone ridges.

In areas where the soils are known to be moderately or very acidic, approximately 60 per cent of farmers have applied some lime, and nearly all are very keen to investigate or try liming in the near future. It is anticipated that most farmers will have applied some lime by the end of 2001.

Ravensthorpe has historically lagged behind other areas of the state in terms of farmer adoption of liming practices. This is primarily due to environmental (physical) and sociological (cultural) reasons, as outlined below.

1. **Lack of awareness**: a very small proportion of farmers are not aware of the threat of soil acidification. These farmers tend to have small landholdings and are not generally considered to be early adopters of agricultural innovations. Having an AGWEST soil acidity contact is useful for overcoming this lack of awareness.

2. **Lack of knowledge**: a number of farmers are confused about soil acidity and acidification, often mistaking soil pH for soil E.C. While most farmers know that some cultural practices are associated with higher rates of soil acidification than others, they are unsure about more technical issues. An example of this is the difference between pH measured in water and in CaCl₂ (compounded by some companies measuring soil pH in water). Divergent views on lime and soil acidification, expressed by some agronomists, further confuse farmers.

3. **Cost**: until recently there has been few lime sources in the Ravensthorpe area. Transport costs from distant lime sources are prohibitive to adoption. Furthermore, due to recent poor years (coinciding with AGWEST’s concentrated extension effort), farmers’ capacity to invest in lime has been reduced.

4. **Soils**: the Ravensthorpe area is unique because soil acidity has not generally extended to depth. While the sandy topsoils are generally moderately acidic, the clay subsoils tend to have mildly acidic to neutral pH. Land has been cultivated for insufficient time for widespread acidity-induced yield penalties to be observed. The extension message in Ravensthorpe tends to be “extension is cheaper than cure”.

5. **Lack of trust**: farmers are suspicious about some claims made by lime suppliers. As a consequence they are wary of investing in lime of doubtful quality.

**CURRENT SUPPLY**

Of the two lime suppliers in the Esperance District, only one has been pro-active in advertising lime (Triple M Transport). A third lime supplier is intending to be fully operational this year (Dalyup). There is only one lime supplier in the Ravensthorpe Shire (Hopetoun Agrilime). The two Magenta-based suppliers are both still operational.

**FUTURE SUPPLY**

There have been several mining lease applications and approvals within the coastal area of Ravensthorpe Shire within the last twelve months. The original purpose of these applications was to mine the existing limestone for use in neutralisation of acidic mine wastes and as road base. There has also been some interest in alternative silcrete neutralising product. Most of the product is being sourced from private (farm) land.

There may be some competition from the mining sector for existing lime supplies, particularly when the Ravensthorpe Nickel Operations mine is in operation (probably within 12 months). This operation predicts that it will be using approximately 300,000 tonnes of lime per year for a period of 20 years. Further dolomite deposits are in the process of being investigated, both on private property and on Crown land.

A coastal limestone ridge south of Springdale Road between Starvation and Mason’s Bays could provide reasonable quality lime in the future – some of this ridge is located on private property and it is possible that mining companies may coalesce with farmers in exploiting these deposits.

Finally, several dolomite deposits have been identified on private land in the Lakes region north west of Ravensthorpe. Farmers have expressed interest in exploring the possibilities of using these resources for application to acid soils on their farms, and three have tested samples.

**CONTACT WITH FARMERS**

Throughout the year, approximately 75 farmers attended one of four local liming/soil acidity presentations. A further 30 visited the soil acidification interactive display at the Ravensthorpe Spring Festival. Twenty farmers have been involved with initiating a lime trial, and 45 farmers are participating in a soil survey and soil acidification extension exercise.

The Ravensthorpe C.A.C. has received approximately 25 phone or walk-in inquiries regarding lime suppliers (location and quality), lime testing businesses, use of lime to
overcome Ca:Mg imbalances, how much lime to apply, setting up on-farm lime trials and interpretation of soil test results.

**FUTURE EXTENSION**

AGWEST will be supporting two new lime trials and two on-farm demonstrations in the district in the coming year. Association with catchment groups makes these trials invaluable as an extension tool. The Fitzgerald/Jacup extension package will be completed by June.

It is anticipated that there will be a three-fold increase in the number of events at which a soil acidification presentation will be given in the southern coastal region (covering Esperance, Ravensthorpe, Jerramungup and Albany Shires). This is an effort to extend the area targeted for liming and soil acidification extension.

**Acknowledgements**

The extension work is supported by growers through the Natural Heritage Trust, the Grains Research and Development Corporation (GRDC) and the Cereals Program and the Pulse and Oilseeds Program of Agriculture Western Australia.

**Key Words**

South coast region, lime use, lime quality
SOIL ACIDITY IN THE GREAT SOUTHERN REGION

Amanda Miller
Agriculture Western Australia, Lake Grace

Historically, soil acidity in the Great Southern has been dealt with relatively poorly. The predominant reason is the lack of identification and recognition that there is a problem with acid soils (particularly acid topsoils) in this part of Western Australia.

In 1998, Porter and Miller estimated the lime requirement of the southwest of WA on a shire-by-shire basis. The Australian Bureau of Statistics also collected data on a shire-by-shire basis through the Commodity Surveys and the Agricultural Census that collects data on lime use. This allowed a comparison of the long-term changes in lime use across the southwest of WA.

Table 1 shows the estimated annual requirement as well as the historical use rate of each shire.

Table 1: Estimated lime requirement per year per shire in the Great Southern versus lime use per shire in 1999/2000 liming season.

<table>
<thead>
<tr>
<th>Shire</th>
<th>Estimated Lime Requirement per year (tonnes)</th>
<th>Lime use 99/00 (tonnes)</th>
<th>Percentage of requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broomehill</td>
<td>5,734</td>
<td>4,150</td>
<td>72%</td>
</tr>
<tr>
<td>Dumbleyung</td>
<td>14,396</td>
<td>3,363</td>
<td>23%</td>
</tr>
<tr>
<td>Gnowangerup</td>
<td>9,575</td>
<td>16,032</td>
<td>167%</td>
</tr>
<tr>
<td>Katanning</td>
<td>7,493</td>
<td>3,571</td>
<td>48%</td>
</tr>
<tr>
<td>Kojonup</td>
<td>23,946</td>
<td>11,486</td>
<td>48%</td>
</tr>
<tr>
<td>Kondinin</td>
<td>14,101</td>
<td>10,276</td>
<td>73%</td>
</tr>
<tr>
<td>Kulin</td>
<td>20,518</td>
<td>5,317</td>
<td>26%</td>
</tr>
<tr>
<td>Lake Grace</td>
<td>26,305</td>
<td>16,438</td>
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<tr>
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<td>716</td>
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<tr>
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<td>9,709</td>
<td>2,319</td>
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Tonnes 168,141 84,174 50%

In 2001, lime use across the shires varies dramatically from just 4 per cent of estimated requirement to a fantastic 167 per cent for the Gnowangerup Shire.

Why is there a widely fluctuating uptake of treatment for acid soils?
Shires that exceed the estimated use rate per year are on the road to recovery. They are treating soils for acidity at a rate that will move them from “salvage” levels i.e. soils below pH 4.5 and soils “at risk” i.e. soils below 5.0, to pHs above 5.0.

By achieving this, Shires are reversing the long-term acidification that has occurred since agriculture began.

For those Shires that have just begun liming there are often a range of reasons for the low level of lime application. These include:

1. Lack of knowledge of acid soils;
2. Historically less area being cropped and therefore less soil testing;
3. Lack of familiarity of the treatment of acid soils i.e. liming.

Whatever the reason, with just 50 per cent of the lime requirement being met on an annual basis, the Great Southern faces a significant challenge in identifying and treating acid soils.

The off site impacts of soil acidity are wide ranging. Figure 1 demonstrates the offsite impacts that occur if soil acidity is not managed.

**Soil Acidity & Offsite Impacts**

![Diagram of soil acidity and offsite impacts]

*Figure 1: Offsite impacts of soil acidity on the environment. Adapted from Porter 1998.*
Over the next year, the “Time to Lime” project, along with other collaborative projects such as the Low Recharge project, will focus on identifying acid soils in the Great Southern and promoting the causes and long-term management.

Acknowledgements
The extension work is supported by growers through the Natural Heritage Trust, the Grains Research and Development Corporation (GRDC) and the Cereals Program and the Pulse and Oilseeds Program of Agriculture Western Australia.

Keywords
Great southern region, lime requirements, offsite impacts
SUSTAINABLE MANAGEMENT OF SOIL, WATER AND NUTRIENTS IN THE HIGH AND MEDIUM RAINFALL ZONE OF WESTERN AUSTRALIA

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\textsuperscript{1}CSIRO Plant Industry, Floreat Park
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\textsuperscript{4}Agriculture Western Australia

BACKGROUND
The need to introduce perennial species into crop rotations in Western Australia to reduce leakage of water below the rooting zone of agricultural production systems and to lower water tables has been highlighted in reviews on the hydrology of the region (see George \textit{et al.} 1997). Recent studies of nitrogen (N) flows under legume-based rotations grown on sandy soils have highlighted the risk of nitrate (NO\textsubscript{3}\textsuperscript{-}) leaching in early winter that contributes to soil acidification (Fillery 2001). Lucerne has been shown to reduce deep drainage in soils in the Great Southern region in Western Australia (Latta \textit{et al.} 2001; Ward \textit{et al.} 2001). There is evidence from studies undertaken in New South Wales that lucerne can also deplete soil NO\textsubscript{3}\textsuperscript{-} in the autumn ahead of opening rains (Peoples \textit{et al.} 2001).

The aims of this work are to determine leakage of water and NO\textsubscript{3}\textsuperscript{-} below perennial-based and annual-based pastures, and indirectly to ascertain their effect on soil acidification when these production systems are grown on acidic soils in the central wheatbelt of Western Australia.

OVERVIEW OF METHODS
The research findings described in this report were obtained from field studies conducted on a deep sand and duplex soil within the Gabby Quoi Quoi Catchment, 18 km south of Wongan Hills. The surface 10 cm of soil at the two sites had a pH of 4.7 in 0.01M CaCl\textsubscript{2} while soil at 15 to 20 cm had a pH of 4 in 0.01M CaCl\textsubscript{2} before lime was applied (3 t/ha) in May 1998. Lime application increased the pH of the top 10 cm of soil to 5.5 (0.01M CaCl\textsubscript{2}) after one year; however, there was no effect of lime application on subsoil pH after 12 months of liming (Mark Whitten, personal communication).

Super phosphate (150 kg/ha) containing cobalt, molybdenum and zinc, and muriate of potash (80 kg/ha) were applied in 1998 and reapplied in 1999 and 2000. Treatments were arranged in a randomised block design with four replicates. Lucerne,
subterranean clover, serradella and perennial grasses were sown in June 1998; serradella and perennial grass treatments were resown in 1999. Annual crops (lupin and wheat/barley) were sown in 1998, 1999 and 2000.

Insecticides and herbicides were used when appropriate to control pests and weed species. Lucerne, serradella and perennial grass pastures were rotationally grazed when needed; subterranean clover-based pasture was either set stocked or rotationally grazed. Pasture production was assessed before and immediately after each grazing event to estimate net dry matter production.

**Soil water content and drainage**
Changes in soil water content were measured using either a neutron probe or using Campbell Scientific frequency domain reflectometers. Neutron probe measurements were used to calculate changes in soil water to 5 m, in this report from November 1999 to December 2000.

\[
D = P - ET - S - R
\]
where \(D\) is drainage (mm), \(P\) is precipitation (mm), \(ET\) is evapo-transpiration (mm), \(S\) is the change in soil water content (mm) to 1.5 m as determined from Campbell frequency domain reflectometers, and \(R\) is runoff. Frequency domain reflectometers were installed in soil at 20, 40, 60, 80, 120, 150 cm under lucerne, subterranean clover and serradella. Evapo-transpiration was either measured using a Bowen ratio or calculated using the Priestly-Taylor equation.

**Soil nitrate and net N mineralisation**
Soil was sampled periodically in depth increments to a maximum of 1.6 m and soil sub-samples analysed for ammonium and nitrate N content. The net mineralisation of organic N was measured on a monthly basis over the growing season by analysing the accumulation of inorganic N in cores incubated at the site.

**N uptake and nitrogen fixation**
The species composition of pastures was measured before grazing. Each species was analysed for total N while legume and capeweed material were analysed for the \(^{15}\text{N}\) natural abundance to assess the proportion of legume N that was derived from atmospheric \(\text{N}_2\).

**FINDINGS**

**Pasture production**
The very poor establishment of perennial grasses precluded any evaluation of this production system. Lucerne-based pasture produced 3.9 t/ha between December 1999 and October 2000 compared to 3.5 t/ha for the subterranean clover-based pasture during the 2000 growing season on the deep sand.
In comparison, on the duplex soil lucerne produced 4.4 t/ha from December 1999 to October 2000 while subterranean clover-based pasture produced 4 t/ha in 2000. These rates of dry matter production were less than recorded in 1999 for lucerne (6.4 t/ha on deep sand and 6.9 t/ha for duplex soil) and subterranean clover-based pasture (6 t/ha on the deep sand and 6.9 t/ha on duplex soil).

Overall, these findings suggest that the introduction of lucerne-based production systems on acidic soils is unlikely to change the pasture production achieved from subterranean clover-based systems. Nevertheless, about 1 t/ha of the lucerne biomass was produced in summer and early autumn in these studies at a time of the year when green feed is at premium value.

**Drainage**

Drainage in 1999 and 2000 below 1.5 m was calculated for lucerne, subterranean clover, serradella and annual crops. Heavy unseasonal rainfall (133 mm) in late March 1999 recharged soil water contents in all pasture treatments and caused drainage of 30 mm below 1.5 m under annual crops and pasture treatments, and 20 mm under lucerne.

Another major rainfall event (103 mm) in late May 1999 increased the drainage below 1.5 m to 90 mm under the annual crop treatment and subterranean clover, and 80 mm under the longer growing season annual, serradella. In contrast, 60 mm of drainage had occurred under lucerne in 1999, confirming that lucerne growth in the autumn and early winter of 1999 had used at least an additional 30 mm of water to 1.5 m compared to the traditional annual crops and pastures. Subsequent below-average winter rainfall in 1999 did not increase drainage significantly.

Little drainage occurred in 2000 under annual crops. Rainfall (75 mm) in late January caused 5 mm to drain below 1.5 m under the serradella treatment and up to 10 mm under subterranean clover and the annual crop treatment. Another 55 mm of rain in late March increased the drainage under serradella to 10-12 mm and up to 20 mm under subterranean clover and the annual crop treatment. It was notable that these summer autumn rains did not wet up soil below 1 m under lucerne. Subsequent below-average winter rainfall in 2000 did not cause further drainage in annual-based production systems.

Neutron probe measurements of soil water content to 5 m over the period 1 December 1999 to 1 November 2000 showed that lucerne removed an additional 70 mm of water compared to subterranean clover. The absolute difference in soil water content to 5 m under lucerne, compared to subterranean clover, was 120 mm in October 2000. The uptake of soil water to 5 m under lucerne confirms the ability of this perennial legume to dewater soil profiles over the summer-autumn period, particularly where growth is supported by summer-autumn rainfall as was the case in both 1998/99 and 1999/2000.

It is also evident from current neutron probe measurements of soil water that little additional water was extracted by lucerne over the summer-autumn 2000-2001,
confirming findings found elsewhere that optimum soil water deficits are likely to be achieved in about two years of establishing lucerne with little further environmental or economic benefit in the retention of lucerne phases past this time.

**Soil Nitrate**

About 60 kg N/ha was in soil to 1.6 m in March 1999 irrespective of pasture treatment. Most of the NO$_3^-$ in soil at 25 March 1999 was present in layers below 0.8 m as a result of 130 mm of rainfall over 15-18 March. Early germination of annual pasture treatments after rainfall in March 1999 resulted in uptake of NO$_3^-$ by annual pastures as well as by lucerne.

In comparison, the quantities of NO$_3^-$ in soil to 1.6 m increased from March to June 1999 where treatments were kept fallow (e.g. wheat after lupin). Less NO$_3^-$ was present in soil to 1.6 m under lucerne compared to serradella, perennial grass-subterranean clover and subterranean clover-based pastures on 10 March 2000.

The difference in the quantity of mineral N in soil (primarily NO$_3^-$) between the annual-based legume systems and lucerne was greater by 2 May 2000 when 36 kg mineral N/ha was under lucerne, whereas soil under subterranean clover pastures contained 72 kg mineral N/ha. Peoples *et al.* (2001) also found that lucerne growing on red brown loams in NSW maintained lower soil mineral N in the autumn compared to annual legume pastures that were fallow at the same period.

The build-up of NO$_3^-$ in soil over the summer-autumn period under annual legumes is a feature of agricultural systems in southern Australia (Fillery 2001). The lower quantities of NO$_3^-$ in soil coupled with the drier soil profiles under lucerne sharply reduce the potential for leaching of NO$_3^-$ from this pasture system, and hence the potential for soil acidification.

**Nitrogen budgets**

Analyses of total N in plant material, including changes in the $^{15}$N natural abundance in legumes and capeweed have been done. These measurements will enable assessment of nitrogen inputs through nitrogen fixation, and N uptake. The rates of net N mineralisation in soil have also been measured thus enabling budgets of N inputs and outflows (NO$_3^-$ leaching and product removal) to be calculated. Analyses of the ash alkalinity content of species are in progress.

**CONCLUSIONS**

Lucerne can be successfully established on acidic sandy soils after surface lime application, and this perennial-based pasture system appears to be as productive as annual-based pasture systems commonly used.

Extraction of soil water to 3 m under lucerne in the first year of growth indicated that lucerne roots were able to grow through strongly acidic subsoil layers. Lucerne-based
production systems reduced the storage of soil profile by as much as 120 mm compared to annual pasture treatments within 28 months of establishment.

Less mineral N was in soil at the onset of winter under lucerne compared to annual legumes in a season where autumn rainfall did not support the early germination of annual pasture species. The lower quantities of NO$_3^-$ in soil together with the sharply lower drainage reduce the potential for soil acidification associated with NO$_3^-$ leaching.

References


Acknowledgments

The support of the Grains Research and Development Corporation (GRDC) is gratefully acknowledged. The Hewson and Siegert families very generously donated land for the conduct of the experiments.
SOIL ACIDITY MANAGEMENT PAYS OFF

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\textsuperscript{2}Agriculture Western Australia, Albany

KEY MESSAGES

- Taking action to manage and treat soil acidity represents an attractive investment over the medium term. Costs of liming are relatively low, while benefits can be sustained for a decade or more. Farmers need to budget on a payback period of at least four years, depending on seasonal conditions and cropping rotation.

- The largest gains in profitability will occur when more acid sensitive crops such as barley and canola are included in the rotation. Excellent responses have also been observed in more acid tolerant crops such as wheat. In addition, liming of acid soils creates new opportunities that may allow farmers to adopt high value, acid sensitive enterprises, either now or in the future, in which case the overall gains from liming can be even greater.

- From a research point of view, up to five years of data has been required to gain an accurate picture of patterns in yield, nutrient status and subsoil pH following liming. Having obtained this information, recommendations can now be provided with a greater degree of confidence than three or four years ago. Other research projects examining long-term issues may need to take a similar outlook, as the results at the end of two or three years may only partially answer the questions of interest.

BACKGROUND

In the Western Australian wheatbelt a large proportion of soil is acidic, and acidifying further due to agricultural production. In many situations, soils have acidified to the point where nutrient tie-up and toxicities associated with low pH are causing significant yield losses. Soil pH readings of 4.5 (CaCl\textsubscript{2}) in the surface (0-10 cm) and around 4.0 in the sub-surface (10-20 cm) are common and, in most cases, are sufficiently low to be costing producers yield and income. Furthermore, poor root growth in the sub-surface as a result of toxic levels of aluminium can reduce water and nutrient uptake and contribute to recharge, salinity and groundwater pollution.

The AGWEST Soil Acidity Project, in collaboration with CSIRO and The University of Western Australia, now has a large base of information regarding the response of several crops to the application of lime to manage soil acidity. Most of the trials and large-scale demonstrations have been running for between five and seven years. One trial is now entering its tenth season and another trial, run by a farmer, has been monitored for 17 years.
This paper is a summary of the responses to liming that have been observed thus far, and a discussion of the main conclusions and recommendations arising from these observations. A range of topics is covered including lime rates, quality, nutritional issues, and financial considerations. It is intended as a helping hand to all those who may be considering including some sort of acidity management in their work. This includes growers who are questioning when they might expect a return on their investment in lime, and agribusiness or researchers wishing to develop and apply knowledge of the effects of liming in their particular area of expertise.

**METHOD**

Lime trials and large-scale lime demonstrations (1 ha plots) have been established and managed for most years since 1994 and 1996 respectively. In addition, one trial has been running since 1991, where the farmer has closely monitored responses to lime since 1984. The trials and demonstrations, which all have rates of lime and are replicated, are located from Northampton in the North to Varley in the East and Esperance in the South. They are concentrated on the more acidic soils, which are generally light textured and acidic at depth. The soil has been monitored for pH changes at a range of depths through the profile. Crop nutrient status and yield response to amelioration of soil acidity have been measured.

Responses by crops to liming in individual trials and economic analyses have been presented in detail in previous Crop Updates (1998, 1999 and 2000).

We have assessed the experimental data that has been generated by the soil acidity project and categorised the response. A summary of the data is presented and the general conclusions and implications for growers and researchers are discussed.

**RESULTS**

Many years of trial and large-scale demonstration data, covering a range of crops, locations, and soil types, has been assessed. The data has been considered to indicate a response to lime where there has been a significant ($p<0.1$) increase in grain yield to the application of either 1 or 2 t/ha of lime (Table 1).

The data from these trials now shows a clear picture of responses, with effects of rotation and season affecting the magnitude of the returns and the profitability of liming. The more acid-sensitive crops of canola and barley tend to respond earlier than the more acid-tolerant wheat crops.
Table 1. Average number of years after liming that first yield response is observed. The data is from small plot trials and large-scale lime demonstrations for the years 1994 - 2000.

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<tr>
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<td>Canola</td>
<td>3 years (3)</td>
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* Numbers in brackets are the number of trials/demonstrations giving a yield response in each of the crops.

In total there are 28 small plot trials and 25 large-scale demonstrations. Of these, only one small plot trial and four large-scale demonstrations remain unresponsive to lime after four years. The reasons for this lack of response have not been identified. There are a further eight trials and 13 demonstrations for which there is insufficient data to draw conclusions at this stage. This lack of data is attributable to crop failures (drought and frost), pasture phases (not closely monitored) and recent establishment of trials (1998). Trials or demonstrations discontinued after one year have not been included in this summary.

CONCLUSIONS

While responses to lime on acid soils appear very variable in the short term (e.g. 1 - 3 years), over the longer term (beyond about 4 years) a consistent picture begins to emerge. This enables general recommendations for farmers and advisors to be provided.

- **Lime rate.** In most cases 1 - 1.5 t / ha every seven to ten years will maximise the overall profitability of a liming programme, although higher rates may be better under strongly acidic scenarios or for ameliorating subsurface acidity. In general, higher rates (e.g. 2.5 t / ha) will maximise profit on a per hectare basis, but will reduce the overall returns because the liming budget cannot cover as many hectares.

- **Payback period.** Farmers and their advisors should budget on a payback period of at least four years. In some cases the payback will be faster, but it is generally unwise to count on it. A farmer who is in a poor cashflow position would be best advised to have only a small liming programme, otherwise the quest for long term profitability may threaten short term viability. On the other hand, a farmer who is in a strong position financially is better placed to address acid soil problems on the farm, and will reap considerable future benefits from doing so.

- **Nutrition management.** Liming can change the availability of some nutrients. In particular, keep an eye on manganese in lupins, and bear in mind that other crops may be affected too. Analyses show that failing to adjust fertiliser regimes can be very costly, whereas the cost of changes to nutrient management are generally small and are easily covered by the gains from liming.
• **Lime test strips and untreated strips in limed paddocks.** Despite its importance, pH has generally not been a good predictor of yield response in WA lime trials. For example, excellent responses were observed at a site near Narrogin where the starting pH (CaCl\(_2\)) was 4.7 in the topsoil and 4.6 in the subsoil, while other more acid sites have taken longer to respond to lime. This variability in response to liming means that it can be a good idea for growers to conduct lime test strips before embarking on a large-scale liming operation, especially if there is a lack of local trial data. A few test strips in each suspect paddock will help in prioritising the application of lime. Test strips will need to be monitored for several years, as it may take some time before a response occurs. Also, when liming a paddock, farmers should leave a strip of untreated land for future comparison; otherwise it will be difficult to tell if the lime has increased yields.

• **Lime quality.** The gains to be made from using good quality lime are considerable. A grower’s decision on which lime to use should be based not only on the costs of purchasing, transporting and spreading the product, but also on quality (neutralising value and particle size).

• **Rotation.** The profitability of liming is strongly linked to the acid sensitivity of the crop being grown, and to the relative profitability of different enterprises. Gains from liming will be greatest where an acid sensitive, high profit potential crop is grown, and lowest where an acid tolerant, low profit potential enterprise is in place. An important elaboration on this is that liming of acid soils creates new opportunities that may allow growers to adopt high value enterprises, either now or in the future, in which case the overall gain from liming will be very large.

**Acknowledgements**

Thanks to Dave Gartner and Sandy Pate for their technical assistance over the years and the many farmers who have assisted with the management of the demonstration sites. This work is funded by AGWEST and the Grains Research and Development Corporation (GRDC).

**Key Words**

Acidity, lime, pH, wheat
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<td>Aglime of Australia</td>
<td>Cervantes</td>
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<tr>
<td>Phone 08 9720 1002</td>
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<td>Lance O’Connor</td>
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<tr>
<td>PO Box 1544</td>
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<tr>
<td>OSBORNE PARK WA 6916</td>
<td>OSBORNE PARK WA 6916</td>
</tr>
<tr>
<td>Phone 08 9446 8644</td>
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<tr>
<td>Fax 08 9244 2071</td>
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<tr>
<td><strong>Lime Industries</strong></td>
<td><strong>Marinoni Dolomite</strong></td>
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<td>Mingenew/Morawa</td>
<td>Kojunup</td>
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<td>Lance O'Connor</td>
<td>Peter Marinoni</td>
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<td>PO Box 1544</td>
<td>PJ &amp; MW Marinoni</td>
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<td>RMB 517</td>
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<td>WA 6916</td>
<td>KOJUNUP WA 6395</td>
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**Phone:** 08 9446 8644  
**Fax:** 08 9244 2071

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<th><strong>Poyner Agricultural Services</strong></th>
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<tbody>
<tr>
<td>Drummonds Cove</td>
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<tr>
<td>Geoff &amp; Karen Poyner</td>
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<tr>
<td>Lot 5 Mullewa Road</td>
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<tr>
<td>PO MOONYOONOOKA WA 6532</td>
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**Phone:** 08 9923 3664  
**Fax:** 08 9923 3440

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<tr>
<th><strong>Nanarup Lime Company</strong></th>
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<td>Nanarup</td>
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<tr>
<td>Quentin Healy</td>
<td>Barry &amp; Tina Versaci</td>
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<tr>
<td>PO Box 1570</td>
<td>29 Third Street</td>
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<tr>
<td>ALBANY WA 6331</td>
<td>HARVEY WA 6220</td>
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**Phone:** 08 9846 4221  
**Fax:** 08 9853 2285

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<td>RSM 736</td>
<td>Keith &amp; Sandra Jackson</td>
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<tr>
<td>COOMBERDALE WA 6512</td>
<td>PO Box 40</td>
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<td>PEMBERTON WA 6260</td>
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**Phone:** 08 9651 8062  
**Fax:** 08 9651 8062

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<tr>
<th><strong>Yarra Sand</strong></th>
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<tbody>
<tr>
<td>Coolimba</td>
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<tr>
<td>Bernard Brand</td>
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<tr>
<td>P O Box 74</td>
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<tr>
<td>CARNAMAH WA 6517</td>
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**Phone:** 08 9951 1064  
**Fax:** 08 9951 1229