Western Australia soil acidity research and development update
1997 : time to lime

Department of Agriculture and Food, Western Australia

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FOREWORD

There is a lot of lime being spread in Western Australia – or is there?

In fact, the Australian Bureau of Statistics agricultural census paints a picture showing that we are still far short of the amount of lime that should be getting on to the ground.

For many years Western Australian soils acidified without significant production penalties. The soil pH was at values that were not affecting plant growth. However, over the last decade or so, large areas of soils have reached the point where production is being affected. In addition, we are now introducing plant species such as canola and the new pulse crops which are much more sensitive to acid soils.

There are still very large areas of soils that need lime applications to remain at, or return to, full production.

The papers in this publication deal with some of the technical information, which allows us to be confident in the decisions being made on managing soil acidity.

The implementation of adequate soil acidity management in Western Australia relies on clear communication between many sectors in the agricultural industries, particularly between land managers, consultants, the lime industry and the Western Australian soil acidity team.

If you have any feedback, a member of the soil acidity team will be pleased to hear from you.

It really is “Time to Lime” in the late 1990s.

Dr W.M. (Bill) Porter
Project Manager – Soil Acidity
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THE SECOND 5 YEARS
$2.5 MILLION COMMITMENT TO PRODUCTIVITY AND SUSTAINABILITY

Dr Bill Porter
Project Manager, Agriculture Western Australia

SUMMARY

Soil acidification is a major threat to the sustainability of Western Australia's grain industries. About two thirds of WA's wheatbelt soils are either acid or at risk of acidification. While many farmers recognise the importance of managing soil acidity, there are significant gaps in the knowledge base that threaten the success of its long-term maintenance.

A multidisciplinary team has been formed to research, develop and promote improved systems for managing soil acidity. An advisory committee including industry representatives is to be formed to oversee the project.

The project team will:
- Investigate methods of slowing the rate of soil acidification;
- Clarify the relationship between the level of subsurface acidity and yield losses;
- Develop techniques to add alkalinity to soil layers that are acidifying.

The team will integrate information generated in the project through:
- Conducting research on shared, intensively managed field sites located across the WA wheatbelt;
- The use of computer models which will, where possible, be developed into predictive tools for use by other stakeholders;
- The economic optimisation of liming and the evaluation of alternative strategies for managing soil acidity.

Recommendations generated in the project will be intensively promoted to the farming community, lime industry and other stakeholders to ensure the sustainable, profitable management of soil acidification in the WA grains industry.

<table>
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<th>Project Title</th>
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<th>Project aims</th>
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| Managing acidity in farming systems | Chris Gazey        | • To identify any unforeseen side effects of applying lime to previously unlimed farming systems in Western Australia and to review the practicalities of liming (e.g. the effect of time on lime spreading).  
• To review and further develop "Optlime" as the basis for a tool for understanding integrated systems.  
• To investigate the potential for liming to increase the diversity within farming systems and the role of acid tolerant crops and genotypes in managing acidity in different farming systems. |
| Promotion of best practice in soil acidity management among farmers | Amanda Miller | • To ensure that the management of soil acidity is understood by all members of the community, and becomes an established component of all farming systems. |
| Economic optimisation of soil acidity management | Andrew Bathgate | • To evaluate proposed activities within the soil acidity project to help researchers decide how best to achieve project objectives.  
• To undertake paddock level analysis of the profitability of different management strategies aimed at reducing the impact of acid soils on production.  
• To document analyses and extend information to development officers, consultants and farmers. |
| Advisory committee for project management | Bill Porter | • To establish an advisory committee that represents key groups with an interest in the management of soil acidity.  
• To assist that committee to review the activities of the WA soil acidity project and make suggestions about future directions for the project. |
| Lime supply quality and availability | Bill Porter | • To assist the lime industry to develop a self-managing QA systems for its products (lime producers) and delivery systems (lime spreaders).  
• To ensure that lime deposits are recognised by planners and the community as an important strategic resource for the economy and environment. |
| Minimising Land Degradation by Soil Acidification | Perry Dolling | To minimise rates of profile degradation in the medium to high rainfall areas of the south west of Western Australia by:  
• Determining rates of profile acidification in the medium to high rainfall areas of the south west of Western Australia  
• Defining and categorising the mechanisms under a number of agricultural systems.  
• Developing agricultural systems that minimise soil acidification. |
| Simple nutrient and acidity calculators for farmers | Art Diggle | • To provide a nutrient calculator for farmers to budget nutrient gains and losses in rotations.  
• To develop a calculator of total acidification in rotations for direct use by farmers.  
• To produce a more complete acidification calculator capable of estimating the effects of rotations for direct use by farmers. |
| Quantifying yield losses due to subsurface acidity | Zed Rengel | • To establish a correlation between subsurface aluminium and crop growth.  
• To develop a computer model, which will enable prediction of yield losses due to subsurface aluminium.  
• To determine effects of water and nutrient availability on the extent of subsurface aluminium related yield losses for different cereal genotypes. |
| Understanding the downward movement of lime for the management of subsurface acidity under different farming systems | Andrew Rate | • To gain a better understanding of lime movement by determining the effects of lime particle size, initial and residual lime reactivity, lime persistence, and tillage and crop residue management on the forms and the rate of transfer of alkalinity to acidity subsurface soil from surface incorporated/applied lime.  
• To provide data for modelling soil acidification and liming in WA, and knowledge to farmers and the lime industry via AgWa extension on the optimal rate and frequency of lime applications for managing subsurface acidity. |
Understanding subsoil acidification

Bill Bowden and C. Tang

- Provide fundamental information on the minimisation or prevention of subsoil acidification.
- Provide important data to model the sub-soil acidification processes which will be used to develop and widely extend management practices to reduce sub-soil acidification.

Sustainable management of soil water and nutrients in the medium rainfall zone of Western Australia

Dr Ian Fillery

- To determine the effect of annual and perennial species on drainage, the input, turnover and fate of legume fixed nitrogen, anion and cation leaching, and soil acidification for a soil in the 400mm rainfall zone.
- To use information on nutrient and water balances to validate wheat/grain legume growth models, to test soil water movement models, and to test predictions of lime movement and lime requirement.
- To devise pasture/crop rotations for improving efficiency of use of water and nutrients.

BENEFITS OF AN INTEGRATED PROJECT

- R & D from an impartial source.
- Sharing ideas within a team focused on the same goals.
- No duplication.
- Sharing of resources.
- Whole farming system approach.
- Keeping research in touch with practical.
- Keeping extension in touch with research.
- Rigour of extension message.

WHO IS IN CONTROL?

Rigorous accountability has been built into the project.

- Both LWRRDC and GRDC have a strong review process for this project. The last review was August 1996.
- Links across agencies helping to provide checks and balances.
- Soil Acidity Advisory Committee to be established at the request of GRDC. The specific break-up of having two landholders (positions to be formally advertised), one Lime industry representative (to be nominated by the Australian Fertiliser Services Association of WA branch), one consultant (to be nominated by the Australian Association of Agricultural Consultants), one GRDC member (to be appointed by GRDC) and one Agriculture Western Australia representative (to be nominated by Agriculture WA). This Advisory committee will rigorously review all work completed on a six monthly basis and provide clear direction and policy for the project.

Acknowledgements

This research project is proudly supported by growers through the Grains Research and Development Corporation (GRDC); the Land and Water Resources Research and Development Corporation (LWRRDC); National Landcare Program (NLP), The University of Western Australia (UWA), CSIRO, Centre for Legumes in Mediterranean Agriculture (CLIMA) and Agriculture Western Australia.
LUPIN/CEREAL ROTATION - NITRATE LEACHING AND SOIL ACIDIFICATION IN DUVLEX SOILS

Perry Dolling
Research Officer, Agriculture Western Australia

SUMMARY
Lupins and wheat are acidifying the soil faster than pasture due to the inefficient use of nitrate under lupins and wheat. In contrast, annual and perennial pastures are able to establish earlier at the break of the season and effectively utilise the nitrate prior to leaching, decreasing the rate of acidification.

BACKGROUND
Soil acidification of the sandy textured soils of Western Australia has been well documented. The major causes of acidification are nitrate leaching and the greater export of alkaline material (plant tops, grain yield). Nitrification is the naturally occurring conversion of ammonium to nitrate during which acidity is produced. If plants take up the nitrate, the acidity is neutralised due to the excretion of hydroxyl ions by the plants, if the nitrate is leached, then the acidity is left in the soil.

TRIAL SITES
A legume/cereal rotation experiment was established in 1994 at Kojonup on a duplex site. A similar rotation experiment exists at Moora on a sandplain site.

Kojonup Site
Soil type: Loamy sand over sandy clay at a depth of 30-40 cm.
Rotations: 1 year lupins / 1 year wheat
2 years annual pasture (clover based) / 1 year wheat
Continuous annual pasture (clover based)
Continuous perennial grass pasture (phalaris and tall fescue)

No nitrogen fertiliser applied except as a treatment in the lupin/wheat rotation in the wheat year.

MEASUREMENTS
- Pasture was grazed using a rotational system with the pasture being maintained between 1 and 3 t/ha dry matter.
- Crop growth was measured at critical crop phases, tillering, anthesis and maturity.
• The nitrate quantities were measured by soil sampling and soil solution sampling; using ceramic cups positioned at different depths.

• Ash alkalinity was measured on any grain removed from the plots to determine the acidification due to the export of alkaline material.

• Soil moisture content was monitored over time.

• Nitrate leached = change in nitrate and ammonium content over time + nitrogen added via the breakdown of organic matter - nitrogen uptake by the plant.

RESULTS

• In 1995 and 1996 acidification was highest in the lupin/wheat rotation due to the greater nitrate leaching when compared to pasture. Acidification due to nitrate leaching occurs in both the wheat and lupin phase.

• Nitrate leaching in the wheat phase can occur before sowing if there has been summer or autumn rain and during the early part of the growing season as the wheat plant is unable to develop fast enough to absorb all nitrate produced from mineralisation and could not access nitrate below 0.6m on the duplex soil.

• Lupins derive 80 per cent of their nitrogen from nitrogen fixation. Therefore any nitrate in the soil is at risk of being leached because the plant is efficient at fixing nitrogen in preference to soil available nitrate.

• The removal of grain product from both the wheat and lupin phase adds to the acidification rate under this system as the alkaline grain from the plots is removed. A 3.9 t/ha wheat yield is equivalent to removing 9kg/ha of lime and a lupin yield of 2.0 t/ha is equivalent to removing 21kg lime/ha.

• Acidification due to nitrate leaching is mainly located in the top 10cm of the soil. Acidification due to removal of alkalinity in produce occurs both in the surface and subsoil (10 - 60cm). It is related to root density and the type and quantity of nutrients in the soil. Although alkalinity removed is low, there is a large amount of alkalinity stored in the stubble indicating there is redistribution of alkalinity within the profile from the subsurface to the surface soil. In 1995 there was 95kg lime/ha (+6 kg lime/ha removed in grain) stored in the wheat stubble and 180kg lime/ha (+21 kg lime/ha removed in grain) in the lupin stubble. Acidification in the subsurface soil is much more difficult and expensive to correct than acidification in the surface soil.

• Pastures (annual and perennial) under normal conditions (not under a late break to the season) have a greater density and the presence of capeweed (50 per cent) (very efficient nitrate user) contribute to a more efficient utilisation of nitrate early, reducing the amount of nitrate leached and reducing the rate of acidification.
• The removal of product in meat and wool and the redistribution of alkalinity within plots via dung and urine are small due to the method of grazing.

• For every kilogram of nitrate leached per hectare as nitrate, 3.6kg of lime/ha needs to be added to the soil to neutralise the acidity produced.

CONCLUSIONS

• Lupins and wheat acidify the soil faster than pasture due to the inefficient use of nitrate under lupins and wheat.

• Total acidification under lupins and wheat in 1995 and 1996 (expressed in the amount of lime required to neutralise the acidity produced) was 175-200 kg lime/ha per year.

• Total acidification under continuous pasture (annual or perennial) in 1995 (expressed in the amount of lime required to neutralise the acidity produced) was 50-75 kg lime/ha, mostly due to nitrate leaching. In 1996 total acidification under pasture, first and second year after wheat was 150-200kg lime/ha. The higher rates of 'lime equivalent loss' in 1996 were due to greater nitrate leaching. The higher rate of nitrate leaching occurred as a result of a false break, late break and heavy rainfall all of which contributed to low plant density and slow plant growth.

Acknowledgements

This research was supported by the Land and Water Resources Research and Development Corporation (LWRRDC); in partnership with Agriculture Western Australia.
LUPIN/ CEREAL ROTATION - NITRATE LEACHING & 
SOIL ACIDIFICATION IN DEEP SANDS

Geoffrey C. Anderson, Ian R.P. Fillery, Perry J. Dolling and Frank X. Dunin 
CLIMA, CSIRO Plant Industry and Agriculture WA

SUMMARY

The amount of nitrate leached is related to how much nitrate is in the soil profile at the 
break of season and the quantity of drainage over the growing season. This is 
determined by the absorption rate at which the growing crops or pastures take up the 
nitrate in the previous season, the intensity of summer mineralisation and the amount 
of rainfall over both of these periods.

Following a relatively dry growing season in 1994, the levels of nitrate in the soil 
profile were higher after lupins when compared to both wheat and pasture. This was 
due to the lower utilisation of soil nitrate by the lupin crop compared to either the 
wheat or pasture.

Heavy rainfall events in May and July of 1995 resulted in high rates of drainage below 
the 1.5 m soil layer and leached 80, 47 and 23 kg NO$_3$ N ha$^{-1}$ from the wheat after 
lupin, lupin / wheat and pasture / pasture treatments respectively. The amount of lime 
required to neutralise the acidity produced as a result of this nitrate leaching were 288, 
169 and 83 kg lime ha$^{-1}$ for the wheat, lupin and pasture treatments respectively.

BACKGROUND

Research is in progress to:

(i) Quantify the input, turnover and fate of legume-fixed nitrogen in grain legume-
wheat and wheat pasture rotations for key soil types in the Western Australian 
wheatbelt;

(ii) Determine the sustainability of legume rotations by evaluating the effect of 
rotations on the soil water flux, water balance, nitrate leaching and soil pH; and

(iii) Use information to calibrate/validate models describing nitrogen cycling in soil 
and crop systems.

Rotation treatments under study include lupin/wheat and two years annual 
pasture/wheat. The research is being conducted on deep sand in an experiment 
located west of Moora.
TRIAL SITE
The rotation experiment was located 11 km west of the town of Moora in the northern Western Australian wheat belt. The soil is classified as yellow sand (Typic, Xeropsamment; Uc5.11; siliceous sand McArthur 1991). Rainfall at the township of Moora is highly variable ranging between 203 to 790 mm with a long-term average of 459 mm over the period 1910 to 1990. The site had been cropped under a lupin/wheat rotation for eight years prior to the commencement of the experiment in March 1994.

MEASUREMENTS
Changes in soil water content were measured using Time Domain Reflectrometry (TDR), while evapotranspiration was measured using the Bowen ratio technique. The quantities of inorganic N in soil were determined at different times of the year by sampling soil to 1.5 m; ceramic suction cups have been used to obtain soil solution, also to a depth of 1.5 m. Biomass production, nitrogen uptake, and nitrogen fixation in legumes, have been determined for lupin, pasture and wheat. Net mineralisation was measured in pasture, lupin and wheat treatments. Drainage was calculated using the following relationship: \( D = P - E - \Delta SW \); where \( P \) is precipitation, \( E \) is evapotranspiration, and \( \Delta SW \) is the change in the soil water to a depth of 1.5 m.

RESULTS
The 1996 growing season at Moora was characterised by a late break to the season with wheat seeding on 18 June. The growing season (18 June to 6 December) received 397 mm of rainfall. Wheat grain yield after two years of annual pasture was 1.9 t/ha\(^{-1}\). Two lupin crops followed, one without fertiliser N and one with returned 2.4 and 2.5 t/ha\(^{-1}\), respectively. Poor weed control in the wheat after pasture treatment reduced grain yields compared to the lupin-wheat rotation treatment. The lupin biomass and grain yield were 5.8 t DM ha\(^{-1}\) and 1.7 t/ha\(^{-1}\), respectively.

Net mineralisation
High rates of net mineralisation were recorded in 1996, compared to the first two years of the study, chiefly because of large legume biomass production (lupin and clover) in 1995, and a summer rainfall event > 40 mm (Table 1). As a result soil profiles following lupin and the second year of annual pasture contained between 120 to 133 kg inorganic N ha\(^{-1}\) when wheat was sown. About 90 per cent of this N was contained in the top 90 cm of soil. In comparison, soil profiles after wheat contained between 75.9 - 80.2 kg inorganic N ha\(^{-1}\), June 18, 1996.

Net mineralisation was dependent on environmental conditions (soil moisture and temperature) and pasture grazing (Table 1). Low rates of net mineralisation in crop treatments (0.2 to 0.4 kg N ha\(^{-1}\) d\(^{-1}\)) occurred over winter when soil temperatures were often less than 15°C. The rate of net mineralisation increased in spring (0.6 kg N ha\(^{-1}\) d\(^{-1}\)) as soil temperatures rose.
The amount of nitrate leached is related to the amount of nitrate in the soil profile at the break of the season and the quantity of drainage over the growing season.

The accumulative rainfall and deep drainage below 150 cm for 1996, and for 1995, are shown in Figure 2. Drainage at 1.5 m accounted for 215 mm of water in 1995 and removed up to 80 kg NO$_3$ N ha$^{-1}$ in wheat plots (after lupin), 47 kg NO$_3$ N ha$^{-1}$ during the lupin phase and 23 kg NO$_3$ N ha$^{-1}$ from under pasture.

Greatest leaching from the wheat after lupin was associated with the higher levels of nitrate within the soil profile at the break of the season. This was due to low uptake of soil nitrate by the growing lupins in the previous season. In contrast, high uptake of soil nitrate by capeweed in both the previous season and early in the current season resulted in lower levels of soil nitrate at the break of the season after pasture compared to lupins. As a result there was less leaching of nitrate from the pasture treatments.

Drainage accounted for 114 mm of water during the period 1 July to 15 September in 1996; which was 100 mm less than the value observed for 1995. The late break in the season in 1996 was the main reason for the lower amount of drainage compared to the 1995 season. Rainfall events after August 15 only added 17 mm to deep drainage. The 141 mm of rainfall between 18 June and 26 July 1996 reduced the soil nitrate content from 97 to 52 kg NO$_3$-N ha$^{-1}$ for the wheat after lupin treatment. Subsequent rainfall and drainage caused the soil profile NO$_3$-N to decline to 31 kg NO$_3$ N ha$^{-1}$ by 14 August. The net effect was an estimated leaching loss of 58 kg NO$_3$ N ha$^{-1}$ for the wheat after lupin treatment.

**Figure 1.** Daily rainfall and deep drainage (mm) at the Moora site between 1 May to 30 October for 1995 and 1996.
Total acidification due to nitrate leaching, expressed in the amount of lime required to neutralise the acidity produced were 288, 169 and 83 kg lime ha$^{-1}$ for the wheat, lupin and pasture treatments respectively in 1995.

**CONCLUSIONS**

These data highlight the poor water use by annual crops grown on deep sands, the associated inefficient use of soil-derived N, and the potential for soil acidification. Alternative crop species and improved management are needed to reduce soil degradation.

**Acknowledgments**

This project was funded by Grains Research and Development Corporation (GRDC) and Land and Water Resource and Research and Development Corporation (LWRRDC); in partnership with the Centre for Legumes in Mediterranean Agriculture, CSIRO and Agriculture Western Australia.
DOES FERTILISATION AFFECT SOIL ACIDIFICATION UNDER LEGUMES?

Dr C. Tang
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The University of Western Australia

SUMMARY
When the supply of potassium sulphate to narrow-leafed lupins and subclover was increased, plant biomass also increased, but the amount of acid produced by each unit of biomass decreased. Increasing calcium nitrate supply to eight legume species showed decreased acid production. The amount of acid produced per unit biomass of nine species increased when the phosphate supply was increased to moderately deficient levels, then decreased further when the supply was increased. Gypsum did not affect acid production of four legume species but decreased the growth of narrow-leafed lupins. Legume species differ greatly in their acid production under various fertiliser regimes. The species effect on soil acidification is greater than the effect of fertilisation.

BACKGROUND
Soil acidification occurs under current farming systems. These studies look at how:
- Applications of potassium and phosphate fertilisers to soils low in potassium and phosphorous (many WA soils), can potentially influence the cation and anion exchange of plants with the soil solution and therefore affect soil acidification;
- Nitrate levels in soil and plant species with differing abilities to take up nitrate, can affect soil acidification;
- The application of gypsum (calcium sulphate) affects acid production by legumes.

GLASSHOUSE STUDY
These glasshouse studies examined effects of the supply of potassium (potassium sulphate), phosphorous (mono-calcium phosphate), gypsum (calcium sulphate) and nitrate ( calcium nitrate) on soil acidification under N2-fixing plants of various legume species grown in sandy soil.

Acidification response to potassium
- Increasing the supply of potassium to narrow-leafed lupins and subclover resulted in an increase in plant growth (biomass) with subclover being more responsive than narrow-leafed lupins.
- Narrow-leafed lupins grown in potassium levels of 30mg/kg soil produced 22 per cent less acid per kg of biomass than lupins grown in the absence of potassium.

- Subclover grown in potassium levels of 120mg/kg of soil produced 33 per cent less acid per kg of biomass than subclover grown in the absence of potassium.

- Increasing the potassium supply to narrow-leafed lupins and subclover increased plant uptake of potassium and sulphur but generally decreased plant uptake of calcium, magnesium, sodium, phosphorous and chloride.

**Acidification responses to nitrate**

- Increasing nitrate supply decreased nodule development of eight legume species. Nodulation of Field pea cv. Wirrega was the most sensitive to increasing rates of soil nitrate. Chickpeas and faba beans were the last sensitive to increasing rates.

- Nitrogen concentrations in plants generally decreased as nitrate levels increased.

- At nil supply, the amounts of acid produced per unit biomass differed by as much as 250 per cent among the legume species. The most acidifying species was the chickpea through to the least acidifying the field pea cv Wirrega in the order of: chickpea > narrow-leafed lupin > yellow lupin > faba bean = albus > field pea cv Dundale = grasspea > field pea cv. Wirrega (Fig 1).

![Graph showing proton excretion rate](image)

**Figure 1.** The amounts of acid produced per kg shoot biomass of eight grain legumes grown at 0, 8, 20 and 80 mg N/ha of calcium nitrate.
• At a given nitrate level, the greater the amount of excess cation uptake by plants, the greater the amount of acid was extruded to the soil i.e. chickpeas absorbed the greatest amount of excess cations and produced the greatest amount of acid.

• With increasing nitrate supply, the amount of excess cations being absorbed increased, while the acid production declined for all eight species. The greatest reduction in acid production occurred in the grasspea and the least reduction in acid production was from the chickpea.

**Acidification response to phosphorous**

• Grains and pasture legumes species differed greatly in their response to phosphorous application.

• Albus lupin, yellow lupin and biserrula had lower external phosphorous requirements than chickpea, faba bean, medic, pink serradella and subclover which in turn had lower requirements than narrow-leaved lupins.

• Increasing phosphorous supplies up to moderately deficient levels increased the amount of acid production per unit shoot biomass. Further increasing the phosphorous level and decreased the level of acid production by the plant.

• Irrespective of phosphorous supply, chickpeas produced the greatest amount of acid.

• A strong correlation exists between total acid production and total content of shoot ash alkalinity regardless of phosphorous supply and plant species.

**Acidification in response to gypsum**

• Application of gypsum did not significantly affect acid production under narrow-leaved lupin, yellow lupin, subclover and pink serradella.

• The application of gypsum at a rate of greater than 250 kg/ha markedly decreased nodulation and subsequently decreased shoot growth of narrow-leaved lupin.

**CONCLUSION**

• To some extent, the supply of fertilisers to legumes does affect soil acidification.

• Acid production under different fertiliser regimes is mainly controlled by the imbalance of cation and anion uptake by plants.

• Legume species differ greatly in their ability to absorb excess cations over anions from the soil solution. This in turn greatly influences the ability of a species to excrete hydrogen ions.
• From this investigation the species effect on soil acidification appears to be greater than the effect of fertilisation.

• The results suggest that selection of legume species and appropriate fertiliser managements are an important component of managing soil acidification.

Acknowledgements
This research is being supported by growers through the Grains Research Development Corporation in partnership with The University of Western Australia and the Centre for Legumes in Mediterranean Agriculture.
LEGUME RESIDUES INCREASE pH OF TWO ACIDIC SOILS

Dr C. Tang, Mr C. Raphael and Dr G. Sparling
Centre for Legumes in Mediterranean Agriculture The University of Western Australia

SUMMARY
The addition of legume residues to the soil is a process of adding alkalinity to the soil profile and thereby increasing the soil pH. The percentage of dissociation of organic acids and/or concentration of organic anions are important in determining soil pH changes when plant materials are added to soil. This information is another piece of the puzzle that will assist in modelling soil acidification to produce a hands-on model for farmers to calculate lime use requirements.

BACKGROUND
Soil acidification has been observed under clover pasture and lupin-cereal rotations. The accumulation of organic matter has been suggested to be one of the causes of that acidification. However in many soil profiles where soil acidification had occurred, it has been found that the most acidifying layers are below 10cm, whereas organic matter is generally accumulated in the top 10cm of the soil. By contrast, alkalisation has occurred in the topsoil after growing legumes in some soils.

INCUBATION STUDY
This short-term incubation study examined the effect of applying clover shoots, clover roots and lupin leaves (differing in nitrogen and organic anion contents) on the pH of two acidic soils collected from Kojonup and Moora. The Kojonup soil was loamy sand over sandy clay with buffer capacity of 1.6 cmol/pH.kg and the Moora soil was yellow sand with a buffering capacity of 0.6 cmol/pH.kg.

RESULTS
Irrespective of incubation time, the addition of the plant materials at a rate of 4 tonnes/ha increased soil pH by up to 0.3 units for Kojonup soil and up to 0.7 units for Moora soil.

Soil pH was at a maximal value at day 0 for the control soil and the soils with clover roots, and at day 7 for the clover shoots and lupin leaves. After reaching maximal value the pH decreased over time for all treatments because of the nitrification process of degrading organic matter that produces hydrogen ions.

The increase in pH of both Kojonup and Moora soils was the greatest with addition of lupin leaves, followed by clover shoots and the least with clover roots (Figure 1).
Addition of plant materials slightly increased the pH buffer capacity of both soils at day 0 but this effect of plant material on the buffering capacity diminished at day 28. At day 0, lupin leaves had the greatest and clover roots the smallest effect on soil pH buffer capacity.

Irrespective of soil types, there was a good relationship between alkalinity created in soils and the amounts of plant excess cations (an indicator of organic anion content) added as plant materials to the soils.

Ammonium concentrations were generally increased by addition of the plant materials. With time ammonium concentration slightly decreased in the Kojonup soil and increased in the Moora soil over time.

Soil nitrate concentrations were similar between plant residue treatments, and increased with time.

CONCLUSION
- The results indicate that the percentage of dissociation of organic acids and/or concentration of organic anions are important in determining soil pH changes when plant materials are added to the soil.
- The study suggests that the application of legume residues, which usually have high excess cations, is not in itself a cause of soil acidification.
- Further study is required to examine the long-term effect of legume residues on soil acidification.

Acknowledgements
This research is being supported by growers through the Grains Research Development Corporation in partnership with The University of Western Australia and the Centre for Legumes in Mediterranean Agriculture.
SIMPLE NUTRIENT AND ACIDITY CALCULATORS FOR FARMERS

Dr Art Diggle, Agriculture Western Australia
Dr James Fisher, Centre for legumes in Mediterranean Agriculture

SUMMARY
This project is collecting information about the rates that different crops remove nutrients and add acid to soils and comes from stores of chemical data measured for the products removed during past agricultural trials. Information is also derived from the results of past projects, many funded by the Grains Research and Development Corporation, which have studied the details of the process of acidification. The collected information will be used to produce simple calculators, which farmers will use to plan the best way to use lime and fertilisers on their farm.

BACKGROUND
Soil acidification and depletion of nutrients are serious problems for agriculture in Australia. They are difficult problems to manage because they occur gradually. There is never a quick change in the productivity of a paddock to indicate to a farmer that the problem has begun to have an effect. Preventative applications of lime or fertiliser, which may be profitable in the long term because they prevent costly decline in productivity, do not have an immediate, obvious benefit. However, if action is not taken until the problems becomes obvious, some loss will already have occurred and if acidity has been allowed to develop in the subsoil, it will not be possible to correct it easily or quickly.

Farmers are well aware of the threats of soil acidity and nutrient depletion, but because they don’t know when these threats will start to affect them, they tend to put off doing anything about them. This project will give farmers the tools they need to work out how the crops that they grow will affect nutrient depletion and acidity on their particular soils. Armed with this information they will have the confidence to act and they will act correctly.

PROGRESS
The first two milestones of this project are: ‘Data from chemical labs compiled’ and ‘Preliminary design of nutrient and total acidification calculators and interface for subsoil acidification calculator’. The database that is required to meet the first milestone has been designed and implemented, and data are being transferred to it from Chemistry Centre computers. The preliminary designs of the calculators are proceeding. Testing of pilot versions of a subsurface acidification calculator and the final version of the same calculator will be completed by June 1999.
PLANS
In the coming year the remaining data will be transferred from the Chemistry Centre and the database will be completed. Development of promising formats for presenting each of the calculators will be finished. Appropriate rules of thumb will be devised, using the chemistry database and published information, to enable farmers to characterise the key factors, which determine nutrient decline and acidification in their situations. These rules of thumb will be incorporated in prototypes of the nutrient and total acidification calculators and testing of these prototypes with farmer groups will begin.

Acknowledgements
This research is being supported by growers through the Grains Research and Development Corporation, in partnership with Agriculture Western Australia and the Centre for Legumes in Mediterranean Agriculture.
RECOMMENDATIONS FOR THE USE OF LIME IN A LUPIN WHEAT ROTATION

Chris Gazey  
*Research Officer, Agriculture Western Australia*

SUMMARY

Three (3) years of intensive field trials have concluded that long-term lupin yields in the wheatbelt have not been significantly affected by the application of lime to acid soils. Providing that the lupins had an adequate supply of nutrients and had good weed and disease management, the major influencing factors on lupin yield were seasonal climatic conditions.

BACKGROUND

In 1993 there was circumstantial evidence of decreased lupin yields from lime application both within trials and from grower reports. This perceived negative response of lupins to lime applications was seen as a major threat and the cause of a potentially serious delay in the adoption of soil acidity technology in the farming system. In response to the initial evidence, this project sets out to determine the cause or causes of lupin yield depression following the application of lime to acidic soils.

TRIAL SITES

Paired trials (one in each phase of the lupin/wheat rotation) were established at more than ten sites throughout the wheat belt. Trials were located at Pindar, Mingenew, Moora, Wongan Hills, Maya, Beverly, South Dangin, South Carrabin, Holt Rock, Newdegate and Green Range.

The trials covered a wide cross section of rainfall and climatic zones. Most of the trials had five rates of lime (0, 0.5, 1, 2 and 4 t/ha) applied in 1994 and four replications; variations included:

- Lime being applied in each of three years to examine the effect of residual lime;
- Cross plot treatments of potassium, manganese or a combination of both;
- Yellow lupins (which have greater acid soil tolerance compared to narrow leaf lupin varieties) were also included for comparison, the results from these trials were reported in the 1996 Lupin Update.

METHODS

The lime was scarified to 10 cm prior to crops of either wheat or lupins being sown. Cu, Zn, Mo-Superphosphate was drilled with the seed at 150 kg/ha and KCl top
dressed at 100 kg/ha at sowing and 100 kg/ha of urea was also applied to the wheat. Comprehensive lupin plant samples were collected from each site to assess plant establishment and plant growth. Grain yield was assessed following machine harvesting at the end of the season. The soils were generally light textured and typical of soils on which narrow-leafed lupins are grown. Soil samples to a depth of 40 cm in increments of 0-5, 5-10, 10-20, 20-30 and 30-40 cm were also collected from each lupin trial approximately six weeks after sowing, using a 50 mm steel tube. The pH (0.01 M CaCl₂) and EC were measured.

RESULTS
A narrow-leafed lupin grain yield related to lime application has been observed in about 10 per cent of the trials conducted. The reason for this yield loss of the order of 10 to 20 per cent has not been identified. However, a depression does not occur every year on an affected site - indicating that the effect could be related to seasonal conditions. Transient depressions in plant biomass have been observed and measured (approximately a 20 per cent reduction in maximum plant biomass) but on three occasions it has failed to have any significant effect on grain yield. Plant biomass response to applied potassium and grain yield response to applied manganese has been observed, but these responses were independent of the rate of lime applied.

RECOMMENDATIONS
- Check soil pH and plant nutrient status regularly especially after liming, including micronutrients.

- Apply lime in the cereal year of the rotation to maximise the chance of an early response to lime by taking advantage of a potential nitrogen flush. A nitrogen flush may occur after initial liming following elevated mineralisation of organic matter as a result of increased microbial activity, which is often associated with a rise in soil pH.

Acknowledgements
This research was supported by growers through the Grains Research and Development Corporation (GRDC); in partnership with Agriculture Western Australia.
EFFECT OF LIME SOURCE AND PARTICLE SIZE ON AMENDING AN ACID SANDPLAIN SOIL IN WESTERN AUSTRALIA

Andrew Speechly, Mark Whitten and Andrew Rate
Soil Science and Plant Nutrition, The University of Western Australia

SUMMARY
Particle size fractions for the lime products were obtained by dry sieving and tested in defined particle size ranges. After 1, 2 and 4 weeks incubation at 20°C G-lime was the most effective liming product at increasing soil pH for every particle size fraction. By week eight, limestone was more effective for finer particle sizes.

Using unsieved lime samples, G-lime was most effective at week one, but limesand was more effective thereafter.

The above ground vegetative biomass of wheat at eight weeks growth was unaffected by either lime source or lime particle size in this experiment.

BACKGROUND
Acid soils are widespread in Western Australia, and the most cost effective method of ameliorating low soil pH is liming. The source of lime is expected to affect the ability of the lime to increase soil pH over any given time period. Particle size, micropore structure and chemical composition will all affect the rate at which lime sources can dissolve in the soil. These factors will consequently affect the products ability to increase the pH of acid soils.

Experimentation using bulk lime samples (unsieved) were used to determine the effect of lime particle size distribution on acid soil amelioration. The sieved lime sources were used to determine the effects of other lime properties on ameliorating low soil pH.

MATERIALS AND METHODS
• Particle size distributions for three lime sources (Agriburnt G-lime, Capel limestone and Dongara limesand) were determined gravimetrically following dry sieving.

• Treatments were unsieved lime and lime in 0.045 – 0.09 mm, 0.09 – 0.125 mm, 0.125 – 0.25 mm and 0.25 – 0.5 mm particle size fractions; each treatment had three replicates.
• Lime neutralising values were determined by reaction with standardised hydrochloric acid (HCl) and back-titration with standardised sodium hydroxide (NaOH).

• Lime (2 t/ha, based on neutralising values) was incubated with Wodgil subsoil (initial pHCa 4.1) at 20°C and 75 per cent of field capacity moisture content.

• Soil pH (1:5 0.01M CaCl\textsubscript{2}) was measured at 1, 2, 4 and 8 weeks following lime application.

• A glasshouse pot experiment growing wheat (cv. Aroona) in Wodgil topsoils amended with the three lime sources, with unsieved and two size fractions (0.045 – 0.09 mm and 0.25 – 0.5 mm) of lime, was also performed.

• Plants were harvested at eight weeks and above ground dry matter yields determined.

RESULTS AND DISCUSSION

Sieved Lime

The particle size distribution of the three lime sources is shown in Figure 1. G-lime was characterised by a high proportion of coarse (<1mm) material; Capel limestone had a relatively even particle size distribution and Dongara limesand had most of its particles in the 0.125 – 0.25 mm size range. Neutralising values for bulk lime samples were: G-lime 104 per cent, limesand 93 per cent and limestone 74 per cent.

![Figure 1. Particle size distribution for lime from three sources determined by dry sieving](image-url)
Lime reactivity decreased with increasing particle size, as expected. Lime effectiveness for any given particle size generally followed the order G-lime>limestone>limesand for one to four weeks of reaction with soil, but was in the order limestone>G-lime>limesand for eight weeks' reaction and small particle sizes.

Regardless of time interval, the smaller the particle size for any of the three lime sources, the more effective the product is at increasing soil pH.

The greater initial increase in pH with G-lime reflects the presence of more soluble $\text{Ca(OH)}_2$ in this lime source. The results from the incubation experiment do not support the idea that limesand is more soluble due to its microscopic structure or chemical composition. The higher pH increases that were observed with bulk (unsieved) limesand were likely to be due to its particle size distribution.

**Unsieved Lime**

The reactivity of lime varied with both source and particle size. For unsieved lime, G-lime increased soil pH quickly after one week, but pH subsequently decreased before rising again. G-lime contains $\text{Ca(OH)}_2$ which reacts more quickly than the $\text{CaCO}_3$ in limestones and limesands. After eight weeks, soil pH (as amended by unsieved lime) was highest for limesand, followed by G-lime and then limestone.

**Biomass**

There was no significant effect of either lime source or lime particle size on above ground wheat dry matter yield determined at eight weeks growth in a glasshouse experiment. All of the three lime sources increased soil pH to similar levels when applied at 2 t/ha, so differences in yield were not expected.

**CONCLUSIONS**

- Lime sources differ markedly in both particle size distribution and neutralising value.
- G-lime is more effective at increasing acid soil pH initially, but limestone and limesand “catch up” in the medium-term.
- Bulk limesand was more effective at increasing soil pH than bulk G-lime or bulk limestone.
- There was no observable effect of either lime source or particle size on wheat biomass at eight weeks in the glasshouse.

**Acknowledgements**

Thanks to Agriburnt Lime, Aglime of Australia and Doyle’s Lime Service for supplying the lime for the experiments.
LIME MOVEMENT: YIELD BENEFIT IN CANOLA FROM AMELIORATING SUBSURFACE ACIDITY

Mark Whitten & Teresa Wozniak
The University of Western Australia

SUMMARY

In 1996, on old land with both surface and subsurface acidity, canola responded to lime applied in 1987 with additional response to re-liming in 1996.

AIMS

Old lime trails (1987-89) were resurrected to determine:
(i) The residual benefit of the original lime applications;
(ii) The extent to which the original lime had ameliorated subsurface acidity;
(iii) The response to re-liming.

METHODS

Lime was applied in April-May 1996 to half of each of the original lime treatments and incorporated with a single cultivation prior to seeding.

The trials were located on yellow sandplain at Mingenew, and duplex sand over clay soils at Cunderdin and Kojonup.

Table 1. Details of lime applied in original trial and re-limed in 1996.

<table>
<thead>
<tr>
<th>Trial No</th>
<th>Location</th>
<th>Soil type</th>
<th>Year started</th>
<th>Lime rates (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kojonup</td>
<td>Duplex</td>
<td>1987</td>
<td>0, 1, 3</td>
</tr>
<tr>
<td>2</td>
<td>Cunderdin</td>
<td>Duplex</td>
<td>1989</td>
<td>0, 0.5, 1, 2</td>
</tr>
<tr>
<td>3</td>
<td>Mingenew</td>
<td>Gradational Sand</td>
<td>1988</td>
<td>0, 1.25</td>
</tr>
<tr>
<td>3</td>
<td>Mingenew</td>
<td>Gradational Sand</td>
<td>1988</td>
<td>0, 2.5</td>
</tr>
</tbody>
</table>

1. Original rates not corrected for neutralising value (NV) which may have ranged from 75-90 per cent relative to pure CaCO3.
2. 1996 lime rate corrected for NV.

- Trial sites were sown to triazine tolerant canola cv TI10 which is similar to Karoo. Due to the late break to the season, seeding was delayed at two sites.
- Fertiliser regime- Super-copper-zinc, 150 kg/ha at seeding; potassium chloride 100 kg/ha and ammonium sulfate 60 kg/ha at four and eight weeks.
• Soil samples were collected in Sept-Oct at 5 cm depth intervals to 40 cm at Mingenew and Cunderdin, or 30 cm at Kojonup.

• Two of the trials were direct-harvested and one was swathed.

• Only the results from Kojonup site have been presented as this site has been cleared the longest and is the most acidified.

**LIME MOVEMENT**

At Kojonup, lime at 3 t/ha in 1987 had increased the subsurface pH to a depth of 20 cm when retested in 1996. This testing also revealed that the soil pH readings at depths greater than 5 cm were below pH 4.5.

Newly applied lime in 1996 had increased the pH to a depth of 10 cm (Figure 1).

![Lime Movement Chart](image)

**LIME RESPONSE**

Newly applied lime in 1996 increased yields by 24 per cent, 29 per cent and 37 per cent where lime had been applied in 1987 at rates of 0, 1 and 3 t/ha, respectively (Figure 2).

The residual benefit of lime applied in 1987 was 13 per cent and 29 per cent for 1 t/ha and 3 t/ha lime respectively, which represents returns of $30 and $70 per hectare.

The benefit, in 1996, of the increased subsurface pH from 3 t/ha lime applied in 1987 was also 13 per cent or about $30/ha.

As lime movement continues, greater yield benefits could be expected at the Kojonup site.
CONCLUSIONS

- On a very acid soil, the response of canola to both newly applied lime and lime applied several years previously has demonstrated the need for (i) liming and (ii) re-liming even if there is still a benefit from the previous lime application.

- The benefit in 1996 of both the original and newly applied lime would more than cover the cost of liming.

- The cumulative benefits from re-liming would be expected to increase if sufficient lime was applied to further increase the subsurface pH over the next few years, and therefore increase profitability.

Acknowledgements
This research was supported by growers through the Grains Research and Development Corporation (GRDC); in partnership with The University of Western Australia and Agriculture Western Australia. We wish to thank Dovuro Oil Seeds for supplying the seed for use in these trials.
WILL LIME CAUSE TRACE ELEMENT DEFICIENCIES?

Mark Whitten
The University of Western Australia

SUMMARY
Lime decreased the leaf concentration of manganese, zinc, copper, and, in one case, boron in canola grown on trials that were re-limed in 1996. These decreases reinforce the need to monitor trace elements when liming to manage subsurface acidity in Western Australia.

AIMS
To determine whether management of subsurface acidity with lime is likely to have side effects on micronutrient deficiencies.

METHODS
The three youngest mature leaves of triazine tolerant canola cv TI10 at re-limed trials in Kojonup and Cunderdin were collected at mid-flowering and analysed for nutrient status. (Refer to “Lime Movement - Yield benefit in canola from ameliorating subsurface acidity.”)

RESULTS
Nutrient availability was affected by increased pH in both the surface and subsurface. Re-liming the highest original lime applications decreased plant tissue manganese (Mn) by 52-60 per cent, zinc (Zn) by 13-19 per cent and copper (Cu) 9-16 per cent. Boron (B) increased by 18 per cent with the original lime only at one site, and decreased by 19 per cent to borderline levels with re-liming at the other site.
Table 1. Trace element concentrations of the 3 recently mature leaves in canola (early to mid-flowering).

<table>
<thead>
<tr>
<th>Location</th>
<th>Lime t/ha</th>
<th>Mn µg/g</th>
<th>Zn µg/g</th>
<th>Cu µg/g</th>
<th>B µg/g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original¹</td>
<td>1996²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kojonup</td>
<td>0</td>
<td>0</td>
<td>163</td>
<td>46</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1.8</td>
<td>113</td>
<td>42</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>118</td>
<td>40</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.8</td>
<td>78</td>
<td>37</td>
<td>5.1</td>
</tr>
<tr>
<td>Cunderdin</td>
<td>0</td>
<td>0</td>
<td>150</td>
<td>36</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1.8</td>
<td>110</td>
<td>33</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0</td>
<td>145</td>
<td>34</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.8</td>
<td>110</td>
<td>32</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>80</td>
<td>29</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.8</td>
<td>58</td>
<td>30</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Adequate range</td>
<td>31-250</td>
<td>22-49</td>
<td>4–25</td>
<td>22-54</td>
</tr>
</tbody>
</table>

1. Original rates not corrected for neutralising value (NV), which may have ranged from 75-90 per cent relative to pure CaCO₃.
2. 1996 lime rate corrected for NV.

CONCLUSION

The decreases in the status of trace elements in canola, highlights the need to monitor crop nutrient status closely when applying lime. Monitoring will become even more important as liming programs reach the re-liming stage and as liming is used to manage subsurface acidity leading to a significant increase in pH throughout the soil profile.

Acknowledgements

This research was supported by growers through the Grains Research and Development Corporation (GRDC); in partnership with the University of Western Australia.
POTASSIUM AND MANGANESE ON LUPINS

Chris Gazey  
Research Officer, Agriculture Western Australia

SUMMARY
Trial data from 1996 shows that the addition of potassium to limed and unlimed soils, which are low in potassium increased plant biomass by 20 per cent but did not affect grain yield. The trial data also shows that in soils low in manganese, a manganese spray prior to main stem flower emergence can increase grain yield by 16 per cent independent of the rate of lime applied.

BACKGROUND
In 1993 there was circumstantial evidence of decreased lupin yields from lime application both within trials and from grower reports. This perceived negative response of lupins to applied lime was seen as a major threat and the cause of a potentially serious delay in the adoption of soil acidity management technology in the farming system. In response to the initial evidence this project set out to determine the cause or causes of lupin yield depression following the application of lime to acidic soils.

TRIAL SITES
Paired trials (one in each phase of the lupin/wheat rotation) were established at ten sites through the wheatbelt.

The trials covered a wide cross section of rainfall and climatic zones. Most of the trials had five rates of lime (0, 0.5, 1, 2 and 4 t/ha) applied in 1994; variations included:

- Lime being applied in each of three years to examine the effect of residual lime;
- Cross plot treatments of potassium, manganese or a combination of both;
- The inclusion of yellow lupins (known for increased acid soil tolerance over narrow-leaf lupin varieties) at several sites for comparison. The results from these trials were reported in the 1996 Lupin Update.

The effects of the cross plot treatments are investigated in this document.

LIME AND POTASSIUM / MANGANESE INTERACTION
The interaction between lime and potassium and/or manganese on narrow-leafed lupin production was investigated in 1996. These two nutrients were identified as likely to be limiting lupin growth in 1995 at several sites on farmers’ properties where lupins suffered depressions following liming. Visual growth depressions following liming were
observed, however, quantitative measurements were not made because suitable histories for the limed areas were not available.

**Maya Site**

In 1996 cross plot top dressing treatments of potassium chloride (KCl) were applied on first year lime plots (limed in 1996 with 0, 1, or 2 t/ha) at Maya. This site had a similar soil type to the farmer sites that showed visual lupin growth depressions in 1995. Soil pH readings are presented in Table 1. The addition of KCl increased plant biomass by 20 per cent regardless of the lime treatment. However, the additional biomass did not alter the grain yield of the lime treatments. The grain yield of 1.75 t/ha was similar for all lime and potassium treatments.

<table>
<thead>
<tr>
<th>Average Depth (cm)</th>
<th>Lime (t/ha) applied in 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2.5</td>
<td>4.80</td>
</tr>
<tr>
<td>7.5</td>
<td>4.18</td>
</tr>
<tr>
<td>15</td>
<td>4.09</td>
</tr>
<tr>
<td>25</td>
<td>4.62</td>
</tr>
<tr>
<td>35</td>
<td>5.29</td>
</tr>
</tbody>
</table>

**South Dangin Site**

At South Dangin, rates of lime were applied in 1993 or 1994 or 1995. At this site cross plot treatments of KCl (top dressed at sowing), Mn (sprayed just prior to main stem flower emergence) and a combination of KCl and Mn were examined. This site was chosen for these treatments in 1996 because the paired site to this one demonstrated a lupin grain yield depression in 1995 of 11 to 28 per cent equivalent to a loss of between 140 to 295 kg/ha where 1 or 2 t/ha of lime was applied in 1993. The yield depression was strongly related to both the rate of lime applied and the length of time for which it had been applied. In 1996 lupins showed no growth or grain yield response to lime. There was however, a highly significant grain yield response to Mn but not K at this site with grain yields increasing from 1.16 to 1.35 t/ha (16 per cent increase) with applied Mn.

**Other Sites in 1996**

In addition to the two sites mentioned in detail above there were also another seven lupin trials (four non-responsive, three abandoned due to poor seedling establishment), three wheat trials (one at South Carrabin was responsive and two non-responsive) and one non-responsive canola trial. During this project 25 per cent of the wheat trials have been responsive with grain increases between 10 and 50 per cent with the addition of 1 to 2 t/ha of lime. Details of the responsive wheat trial at South Carrabin are presented here for balance.

The trail at South Carrabin research annex was limed in 1994, and sown to wheat (non-responsive with a yield of 1.0 t/ha). In 1995 average narrow-leafed lupin yield
was 0.71 t/ha and there was no response to applied lime. In 1996 the wheat responded significantly (Table 2). Soil pH data are presented in Table 3.

Table 2. Grain yield (t/ha) of wheat at South Carrabin Research Annex in 1996 on lime (t/ha) which was applied in 1994 (Trial 96ME39).

<table>
<thead>
<tr>
<th>Lime (t/ha)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.21a1</td>
</tr>
<tr>
<td>0.5</td>
<td>2.46ab</td>
</tr>
<tr>
<td>1</td>
<td>2.63b</td>
</tr>
<tr>
<td>2</td>
<td>2.62b</td>
</tr>
<tr>
<td>4</td>
<td>2.75b</td>
</tr>
</tbody>
</table>

1 numbers followed by the same letter are not significantly different (P² 0.05)

Table 3. Soil pH at South Carrabin Trial (94ME39) measured in 1:5 0.01M CaCl₂

<table>
<thead>
<tr>
<th>Average Depth (cm)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>4.70</td>
<td>5.89</td>
<td>6.33</td>
<td>6.83</td>
</tr>
<tr>
<td>7.5</td>
<td>4.10</td>
<td>4.24</td>
<td>4.52</td>
<td>5.10</td>
</tr>
<tr>
<td>15</td>
<td>4.21</td>
<td>4.03</td>
<td>4.26</td>
<td>4.33</td>
</tr>
<tr>
<td>25</td>
<td>4.40</td>
<td>4.10</td>
<td>4.35</td>
<td>4.32</td>
</tr>
<tr>
<td>35</td>
<td>4.45</td>
<td>4.06</td>
<td>4.43</td>
<td>4.26</td>
</tr>
</tbody>
</table>

RECOMMENDATIONS

- Check soil pH and plant nutrient status regularly especially after liming, including micronutrients.

- Apply lime in the cereal year of the rotation to maximise the chance of an early response to lime by taking advantage of a potential nitrogen flush. A nitrogen flush may occur after initial liming following elevated mineralisation of organic matter as a result of increased microbial activity, which is often associated with the rise in soil pH.

Acknowledgements

This research was supported by growers through the Grains Research and Development Corporation (GRDC); in partnership with Agriculture Western Australia.
OPTLIME - THE ECONOMICS OF LIMING

Andrew Sandison and Andrew Bathgate
Agriculture Western Australia

SUMMARY
Optlime is a Microsoft Excel 5 spreadsheet that operates in a Microsoft Windows environment. The model runs over a 30 year time frame and compares the cash flows for limed and unlimed lupin/wheat or pasture/wheat rotations. The model splits the soil into two layers, a topsoil layer and a subsurface layer. The model can be used to optimise liming rates and application times in order to maximise returns over the term of the rotation.

Within the model, wheat production is sensitive to declining pH. As pH falls aluminium concentrations increase in the subsurface and depress wheat yields. Pasture and lupin production are assumed not to be sensitive to aluminium toxicity.

BACKGROUND
Soil acidification and in particular subsurface acidification of light textured soils in Western Australia is a major threat to production. Before farmers adopt methods for managing soil acidity they will need to be convinced of the profitability of doing so. While there are gaps in technical knowledge on issues regarding the management of soil acidification, particularly subsurface acidification, the level of knowledge is adequate for modelling possible scenarios. Modelling can highlight the more important factors affecting the profitable management of subsurface acidification to researchers and inform farmers as to their likely costs and benefits from managing subsurface acidification.

SCENARIO
Farmers are likely to experience declining returns from their sandplain soils now or some time in the future as the subsurface of their soils continues to acidify. The losses in income are likely to be large as seen in Figure 2. These losses however may take some time to become apparent due to the slow rate of pH decline.
Viewed over the longer term, the size of the possible losses that farmers’ face are considerable and should provide significant incentives to find solutions to subsurface acidification. Farmers with soils, which have acidified to a pH where wheat production is affected can expect increased yields and profits if they raise the subsurface pH.

**ASSUMPTIONS**

Model assumptions are as follows:

**Table 1**: The yield, price and production costs assumptions used in the model.

<table>
<thead>
<tr>
<th>Farm Gate Prices</th>
<th>$/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>wheat</td>
<td>125</td>
</tr>
<tr>
<td>lupin</td>
<td>145</td>
</tr>
<tr>
<td><strong>Average yields</strong></td>
<td>T/ha</td>
</tr>
<tr>
<td>wheat</td>
<td>2.0</td>
</tr>
<tr>
<td>Lupin</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Variable costs of production</strong></td>
<td>$/ha</td>
</tr>
<tr>
<td>1st Wheat</td>
<td>85</td>
</tr>
<tr>
<td>Lupin</td>
<td>90</td>
</tr>
</tbody>
</table>

★The wheat yields that would be possible if there was no production losses due to acidity.
Table 2: Liming costs and properties that were used in the model.

<table>
<thead>
<tr>
<th></th>
<th>$/tonne</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime cost at pit</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>Freight distance</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Freight rate</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Spreading cost</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Freight cost</td>
<td>15.00</td>
<td></td>
</tr>
<tr>
<td>Total cost of lime</td>
<td>30.00</td>
<td></td>
</tr>
<tr>
<td>Lime neutralising value</td>
<td>90%</td>
<td></td>
</tr>
</tbody>
</table>

**LIMING STRATEGIES – HOW DO THEY AFFECT THE MODEL**

With the current levels of knowledge about liming, it is not possible to accurately predict the liming requirements of different sandplain soils in different regions. The current recommendation of 1-2 t/ha lime every 7-10 years to sandplain soils with pH below approx. 4.5 - 4.8. Table 3 compares the profitability of liming at five rates of lime on the basis of application one year in ten.

Liming rates between 1-2 t/ha/10 years were generally comparable with the optimal liming strategy given that it is not possible at this time to identify whether soils are highly or moderately aluminium toxic.

In this situation liming at rates between 1-2 t/ha/10 years is equivalent to annual costs of between $3.50 and $7.10/ha.

**COST OF DELAYING LIMING**

Gross margins will be considerably smaller if liming is delayed when yields are affected by subsurface pH. This can be seen in Table 4 where liming is delayed by five years on a highly aluminium toxic soil and a moderately aluminium toxic soil. Given a subsurface pH of 4.1 on a highly aluminium toxic soil, delaying liming...
practices by five years will decrease the long term gross margin from $97/ha/yr to $86/ha/yr.

In all but one case in Table 4 it is more profitable to begin liming now rather than delaying liming for pH in the range between 4.3 and 3.9. In the worst-case scenario liming breaks even while there is a potential for liming to increase rotational gross margins in the order of $20/ha/yr.

This model accounts for the value of money. A scenario breaking-even represents a 7 per cent real rate of return on the investment in lime.

CONCLUSIONS

- Optlime will be undergoing further development in the next few years as research "fills in" some of the gaps in knowledge.

- At this point of time the model supports the current lime rate recommendation of 1-2 t/ha of applied lime every 7-10 years to ameliorate soil acidity.

- Scenarios generated by the model generally reinforce the fact that the cost of liming too early (before pH is limiting production) is outweighed by the potential losses by liming too late (when pH is limiting production).

Acknowledgments

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