CURRENT PRACTICES AND EXTENSION ON ACIDIC SOILS IN WESTERN AUSTRALIA

Andreini, M and Dolling, P. J.
Department of Agriculture Western Australia

This document describes the current practices being conducted by Government based organizations on acid soils. The report highlights the research and extension programs being conducted by Government and the code of practice and quality assurance programs being conducted by industry.

EXTENT OF PRACTICES

There are predominantly four techniques that Western Australian land managers use to manage soil acidity. These are:

- Application of liming material
- Use of acid tolerant plants
- Use of management practices which reduce the rate of acidification to a minimum
- Application of other types of neutralising agents

1. Application of lime material

Within Western Australia (WA), liming materials are predominantly agricultural limes (naturally occurring crushed or sieved limestone and lime-sand) and dolomite (crushed or sieved deposits of calcium and magnesium carbonate). A calcium oxide and calcium carbonate product produced as a by-product of cement manufacture is also used as a lime source.

Estimates of production/use

Agricultural lime use based on surveys by the Australian Bureau of Statistics (ABS) has increased by fifty four thousand tonnes (46%) per year over 10 years from 1989/90 to 1998/99 (Figure 1).

Most of the increase has however, occurred in the last three years, with an average increase of 89% per year. This increase can be attributed to the introduction of the '*Time to Lime*' campaign by Agriculture Western Australia in January 1996. The introduction of the program has resulted in an increased awareness of the effects of soil acidity and the benefits of liming. This increased awareness coupled with favourable seasons over this period has had a synergistic effect on the amount of lime used.

The areas that have a higher percentage of the land in crop (the Statistical Divisions of Upper Great Southern, Midlands and Central, see Figure 2) have shown the greatest increase in lime use from 1994/95 to 1998/99 (Table 1). In comparison, the areas that have a higher percentage of the land in pasture (the Statistical Divisions of South West and Lower Great Southern) have shown a smaller increase in the percentage of lime use over the same time period (Table 1).

Data from ABARE supports this conclusion; they have surveyed Australian broad acre cropping and dairy industries on the use of lime and gypsum. In 1997, the ABARE data for the eastern half of the Statistical Divisions of Upper Great Southern, Midlands and Central showed 100% use of these ameliorants on land being sown under crop. Excluding the South Eastern statistical division 17% of the farmers in each region in 1998/99 year used lime (range 11-20%). Only 3% of the farmers in the South Eastern division used lime.

The area of agricultural land being treated with lime has shown a similar increase to the amount of lime being used over the last 10 years. In 1998/99 five hundred and eighty-six thousand hectares were limed. Average lime use is currently 1.1 tonnes per hectare, and this has not varied greatly over the last 10 years.

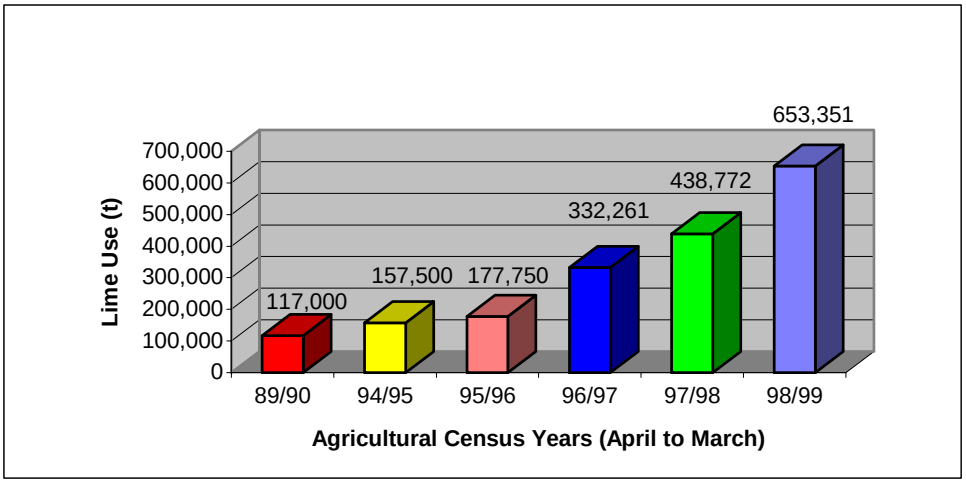

Figure 1: Lime Use in Western Australia for agriculture purposes (includes all sources of lime) from the Australian Bureau of Statistics (Miller 2000)

Table 1: Regional summary of estimated lime used in thousand of tonnes for each Agro-Ecological region (AER) and statistical divisions (ABS). The values in parenthesis represent the relative standard error [A]

AER Region	ABS Region	94/95	95/96	96/97	97/98	98/99
Wet Temperate coasts	South West	35	33	36	44 (4)	70 (11)
Wet Temperate coasts	Perth	3	3	5	3 (6)	9 (11)
Wet Temperate coasts	Total	38	36	41	47	79
Temperate slopes & plains	Lower Great Southern	37	34	55	52 (11)	97 (9)
Temperate slopes & plains	Upper Great Southern	17	10	38	61 (11)	101 (13)
Temperate slopes & plains	Midlands	42	49	121	148 (7)	205 (6)
Temperate slopes & plains	Central	20	48	81	127 (9)	166 (6)
Temperate slopes & plains	Total	116	141	295	388	569
Arid Interior	South Eastern	3	0	1	3 (35)	7 (29)

[A] The relative standard error is obtained by expressing the standard error as a percentage of the estimate to which it refers

Lime used in the South West is mostly limestone, while lime-sand is mostly used in the Midlands, Central and Upper Great Southern Divisions. Lime used in the Lower Great Southern Division is both limestone and lime-sand. Approximately 10% of the total lime used in WA is in the form of dolomite and is used predominantly in the Lower and Upper Great Southern regions. Burnt lime, a by-product from the cement industry, supplies approximately 5-10% of lime used in WA.
The agricultural lime industry is only a small industry in comparison to that providing the lime used by the mining, construction and road construction industries. The Department of Minerals and Energy of WA (DME) has estimated that Western

Australia's lime production in 1999 was 3 million tonnes. The amount of limestone and lime-sand used by the agricultural sector in WA during 1999 was 0.233 million tonnes (5% of the total lime consumed). However, a large amount of lime used for agricultural purposes remains unreported, as private land extraction of lime in WA does not attract a government royalty. The cement and alumina industry consumed an estimated 21% and 20% respectively of lime in 1999 with mineral sands and gold using another 17%. The remaining 40% was consumed mainly in low-grade applications such as road base, construction, and building blocks.

Figure 2: Australian Bureau of Statistics statistical divisions

Agricultural Lime Quality

Most of the lime-sand and limestone pits are located along the south and west coast. Dolomite is mined inland from lake deposits.

The average neutralising value of lime-sand sold in WA (registered pits only) is 87% (range 64-95%); the average particle size is 90% less than 0.6 mm (range 57-100%) and it contains 33% and 1.5% calcium and magnesium, respectively.

In comparison the average neutralising value of limestone sold in WA (registered pits only) is 78% (range 69-90%), the average particle size is 67% less than 0.6 mm (range 35-87%) and it contains 30% and 1.0% calcium and magnesium respectively.

Dolomite sold in WA (registered pits only) has an average neutralising value of 69% (range 39-97%); the average particle size is 33% less than 0.6 mm (range 17-52%) and it contains 15% and 8.3% calcium and magnesium respectively.

Table 2 contains data on the lime quality of 13 of the 29 pits registered in Western Australia. The quality data can be taken as a guide only, as the quality will vary due to the nature of the product.

Lime costs
Lime-sand is generally sold for $4.50-$7/t for
Crushed limestone is normally sold around $8.50-$18/t
Dolomite is sold for around $18-$30/t
Burnt lime is generally sold around $17/t

Lime Spreading Costs
Generally around $8-10/t

Lime Cartage Costs
Cartage costs in the mid 1990s were approximately $0.10 per kilometre per tonne and this fell to $0.05 to $0.07 per kilometre per tonne in the late 1990s. Rising fuel prices in 2000 will see freight rates increase again to $0.07 to $0.10 per kilometre per tonne.

Value of the Lime Industry
Using 1998/99 ABS figures of lime used in WA, the estimated worth of lime to industry was $22 .9 million dollars. This is based on an average cost of $10/t for lime, $15/t for cartage and $10/t for spreading.

2. Use of acidic tolerant plants
In WA, the use of acid tolerant plants is often seen as a viable option on naturally occurring highly acidic soils, as it is often not cost effective to apply lime. Naturally occurring acidic soils occur in the Central and Midlands Statistical Divisions (Wodjil soils) and, because of the cost of lime, farmers grow acid tolerant species such serradella, triticale, oats and yellow lupins.

3. Use of less acidifying management practices.
There are a number of management practices that are capable of reducing the acidification rate of soils and their adoption through WA has varied. The use of less acidifying forms of fertilisers is becoming common in many of the perennial horticultural crops such as grapes and orchids where calcium nitrate is being used. It is estimated that half of the viticulturists in WA are currently adopting the practice, as it is cost effective, due to the nitrogen requirements of grape production. In broad acre farming, calcium nitrate is too expensive and therefore is not considered an option. However, ammonium based fertilisers (3.6 kg lime per kg nitrogen applied is required to neutralise the acidity, assuming no leaching of nitrogen) are more acidifying than urea (no lime required, assuming no leaching of nitrogen). On this basis some farmers have changed to using urea, but choice of nitrogen source can depend on other factors such as price and ease of use.

The adoption of deep-rooted perennial pastures is being adopted in WA. There is approximately 50 000 ha currently under lucerne. The establishment of lucerne is generally encouraged for its rooting ability, water use, summer activity, pasture quality and the ability to reduce the amount of N leached through the soil profile, slowing the rate of acidification.

Other perennial species such as phalaris, kikuyu, perennial veldt grass and tall wheat grass are being adopted especially on the Esperance sand plain in the less than 600mm rainfall zone. These perennial plants have a number of environmental benefits; one being that their extensive root systems can reduce the rate of acidification and increase overall productivity.

RESEARCH AND EXTENSION PROGRAMS ON ACID SOILS

Extension Programs

Agriculture Western Australia is currently carrying out a Natural Heritage Trust funded soil acidity extension project aimed at increasing the awareness and adoption of acid soils technology in WA; includes soil testing and liming, developing industry ownership and management of soil acidification. This project was launched in January 1996 and is referred to as the '*Time to Lime*' project.

Extension of knowledge and information is also a large part of the 'Soil Acidity Management in Western Australia – an integrated project', which is a jointly funded project between GRDC, Agriculture Western Australia, CSIRO and The University of Western Australia.

Information that is derived from the research carried out by these organizations is extended via Agriculture Western Australia extension officers, as well as the respective organizations, through such avenues as:

- Survey of land holder usage of lime
- Farm information sheets (Farm Notes)
- Annual research and development and extension reports
- Workshops to improve the understanding of agribusiness
- Presentations by extension officers and research officers at field days,
- Information provided by 'Cropline', a telephone service for farmers.

Support tools

There are a number of specific support tools that are available to assist in making decisions about applying lime and the effects and benefits of managing soil acidity.

The 'Lime Information Kit' explains what lime is, why lime should be used, where to get lime, when to apply lime and how to store and apply lime. The kit was available from all Agriculture Western Australia regional offices and the Kondinin Group, but is currently out of print.

The lime and nutrient calculator was first released in 1998 and was designed as a support tool in estimating the maintenance requirements for lime and nutrients. The calculator predicts the quantities of liming materials and nutrients that are leaving the paddock after various cropping and pasture rotations under various soil types.

Optlime is a model that investigates the long term benefits and costs of managing soil acidity, combining biological responses with benefit cost analysis, and is able to compare the profitability of different management strategies over a 30 year period. The model is available to consultants, researchers and Agriculture Western Australia extension officers after appropriate training at workshops (refer to Table 3 for further extension material available).

Agribusinesses in WA also offer extension, such as soil testing kits, to manage soil acidity.

Quality assurance in WA

The Australian Fertiliser Services Association (AFSA) is a professional body that represents individuals and industries involved in the fertiliser and lime industries through out Australia. In 1995 the AFSA decided to further promote the activities and the image of the fertiliser industry. It had been acknowledged that there was a real need to ensure that fertiliser and soil ameliorants (lime), transport, spreading and agronomic advice was quality controlled. Therefore, in 1997 the AFSA, in conjunction with Natural Heritage Trust funding, developed the Fertiliser Industry Code of Practice. This code of practice aims to maximise economic returns for members and clients whilst at the same time minimising the negative environmental impact associated with the use of fertilisers.

The AFSA in Western Australia has been developing the Quality Assurance System for the fertiliser industry and has formed an alliance with Agriculture Western Australia to use the Safe Quality Food (SQF) 2000 quality assurance system.
It is estimated that in 2001, WA will see the first of the AFSA quality assured transport and spreader operators and the first AFSA quality assured lime suppliers.

In July 1999 the AFSA in conjunction with the "*Time to Lime*" campaign, embarked with Industry on a project to develop a specific Agricultural Lime Industry Code of Practice and this was released in October 1999. Since that time the AFSA has been working on the development of new lime quality standards for WA including all new testing and reporting procedures. Thirty lime suppliers (representing 90% of agricultural lime supplied in WA) are currently operating under the Agricultural Lime Industry Code of Practice.

Research

Currently research into soil acidity management in Western Australia is being carried out by four collaborating organizations: Agriculture Western Australia, the University of Western Australia and CSIRO with support by GRDC (refer to Table 4 for contact details). These organizations have invested $6.5m into this five-year research project, which commenced in 1997.

At Agriculture Western Australia the main areas of research include:

- Managing acidity in farming systems
- Economic optimisation of soil acidity management

At the University of Western Australia the main areas of research include:

- Quantifying yield losses due to subsurface acidity
- Understanding the downward movement of lime for the management of subsurface acidity under different farming systems
- Understanding sub-soil acidification

At CSIRO current research includes examining sustainable management of soil water and nutrients in the medium rainfall zone of Western Australia.

Historical research

There has been a large number of research projects carried out in WA including lime responses in barley, wheat, lupin and subterranean clover. Research has also been conducted into acidification, the impact of aluminium toxicity on growth and the leaching of lime through the soil. Table 6 outlines some of the scientific papers produced from research conducted in Western Australia on acid soils.

References

Western Australian Soil Acidity Research and Development Updates 1998-2000 (including the paper of Miller)
Industrial Minerals, Issue 393, June 2000
This report was compiled with the assistance of Cheranne Morris (Teamwork Outsourcing representing the AFSA), David Gartner, Amanda Miller, Daniel Lamb, Chris Gazey and Neil Lanzke (all from AGWEST) and Alison McClenaghan (ABS, Tasmania)

Table 2 Summary of the latest lime quality results collected from 13 of the 39 registered lime pits in Western Australia (AFSA, AGWEST).

Lime Supplier - Pit Location	GPS References		Product Description	Overall NV%	Particle Size Distribution										Ca %	Mg %	Na %
					0-0.125mm		0.125-0.25		0.25-0.5mm		0.5-1.00mm		> 1.00mm				
	E	N			% Wt	NV %	% Wt	NV %	% Wt	NV %	% Wt	NV %	% Wt	NV %			
Aglime of Australia -Lancelin	342263	6565540	Lime-sand	92.1	3.5	91.7	60.5	89.6	30.3	94.9	5.5	82.7	0.1	69.4	34.6	1.8	0.26
-Cervantes	316712	6624978	Lime-sand	94.5	5.7	93.5	73.2	92.6	19.5	96.2	1.6	88.7	0.1	86.8	35.8	1.8	0.25
-Jurien Bay	312057	6652231	Lime-sand	91.2	3.8	88.9	62.5	89.6	30.6	92.4	3.1	86.4	0.1	82.9	34.0	1.8	0.25
-Dongara	298442	6758761	Lime-sand	95.2	18.4	93.8	75.6	95.1	5.3	90.6	0.6	77.7	0.1	61.9	35.3	1.8	0.32
Beaufort River Dolomite -Beaufort River	504723	6284857	Dolomite	69.2	6.5	71.4	10.6	67.3	13.7	66.8	18.7	67.5	50.5	68.0	13.4	9.0	1.6
Cockburn Cement -Munster	387277	6443266	Burnt Lime	104.8	25.2	105	9.2	103	11.0	102	12.7	104	41.7	105	39.0	2.2	0.61
Doyle's Lime Service -Myalup	378283	6351667	Limestone	73.1	7.3	63.7	54.3	68.1	25.7	82.0	8.9	83.6	3.7	80.1	28.0	1.4	0.18
Lance Lime -Myalup	379139	6345250	Limestone	81.6	12.7	89.5	33.1	79.4	25.5	83.9	18.9	73.3	9.8	90.0	31.4	1.2	0.15
Nanarup Lime Company -Nanarup	595447	6128930	Limestone	90.1	6.8	87.8	9.5	90.1	33.0	90.2	20.7	90.3	29.9	90.7	34.4	0.48	0.02
K & P. M. Green -Lake Magenta	710464	6298318	Dolomite	71.1	17.6	73.6	16.4	61.2	17.8	54.8	14.0	63.2	34.1	84.0	13.2	9.4	0.28
Poyner Agricultural Services -Drummonds Cove	266475	6828945	Lime-sand	68.2	2.9	83.8	67.9	73.7	26.6	53.7	2.5	47.5	0.1	58.3	25.6	1.3	0.13
SuperFert Pty Ltd -Kwinana	-	-	Crushed Lime-sand	92.1	61.8	92.8	34.0	88.8	3.9	88.4	0.2	91.8	0.1	90.8	35.4	1.8	0.27
Yarra Sand -Coolimba	305288	6698531	Lime-sand	92.7	1.8	92.1	35.0	93.2	50.2	92.1	12.9	89.2	0.2	87.9	35.7	2.0	0.22

KEY: NV = Neutralising Value, Wt = Weight, Ca = Calcium, Mg =Magnesium, Na= Sodium, Lime = Calcium Carbonate, Dolomite = Calcium Carbonate + Magnesium Carbonate. All sieving undertaken on a dry product basis

Table 3: Extension material and tools available on soil acidity and liming available from Agriculture Western Australia.

Extension Title/Tool	Reference:
Farm notes	
Soil acidity and barley production	79/2000
Looking at liming-quality	67/2000
Management of soil acidity in agricultural land	80/2000
Importance of soil pH	78/2000
Looking at liming – test strips	68/2000
Looking at liming – consider the rate	70/2000
Looking at liming – comparing lime sources	In Print
Enhancing soil processes 48/96	48/96
Tolerance of wheat varieties to soil acidity 2/96	2/96
Liming of subclover pastures in acidic soils 84/86	84/86
Bulletins	
Monitoring and managing soil acidity	
Liming acid soils: a break-even analysis	4289
Miscellaneous publications	
Increasing the value of rotation by liming 2000 Crop updates	
Soil acidity research, development and extension update 1997	
Soil acidity research, development and extension update 1998	
Soil acidity research, development and extension update 1999	
Soil acidity research, development and extension update 2000	
Soil acidity research, development and extension update 2001	
Soil Acidity A Reference Manual	ISSN 0725-847X
Time to lime. WA soil acidity demonstration results 1996 to 1999 -	ISSN 1326-4168
Wheat responses to Soil acidity	
Extension tools	
Lime And Nutrient Calculator For WA	
Optlime Model	
‘Time to Lime’, Lime Information Kit	

Table 4: Summary of current research projects being undertaken in Western Australia, the objectives and the researchers involved

Research project	Objectives/aims	Researchers
Managing acidity in farming systems (AgWA1)	• Identify side effects of applying lime to previously un limed farming systems in WA and review the practicalities of liming • Review and develop 'Optlime' as a tool for understanding integrated systems • Investigate the potential for liming to increase the diversity within farming systems and the role of acid tolerant crops in managing acidity.	Mr Chris Gazey (AGWEST) Mr Dave Gartner (AGWEST) Ms Teresa Wozniak (UWA) Ms Sandy Pate (AGWEST)
Economic optimisation of soil acidity management (AgWA3)	• Evaluate proposed activities within the WA soil acidity project to help research decide how best to achieve project objectives • Analyse at a paddock scale the profitability of different management strategies aimed a t reducing the impact of acidic soil on profitability • Document analysis and extend information to development officers, consultants and farmers.	Mr Michael O'Connell (AGWA)
Advisory committee for project management (AgWA4)	• Establish an advisory committee representing key groups who share an interest in the management of soil acidity • Assist the committee to review the activities of the WA soil acidity project and have input into future directions.	Mr Chris Gazey (AGWEST) Dr Ian Fillery (CSIRO) Assoc. Prof. Zed Rengel (UWA)
Quantifying yield losses due to sub-surface acidity (UWA1)	• Establish a correlation between subsurface A1 (acidity and crop growth) • Predict yield losses due to subsurface acidity using APSIM • Investigate the relationships between yield losses due to subsurface acidity and water and nutrient availability • Determine the level of resistance to subsurface A1 of various cereal crops	Dr C. Tang (UWA) Assoc. Prof. Zed Rengel (UWA)
Understanding the downward movement of lime for the management of subsurface acidity under different farming systems (UWA2)	• 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 on the forma and rat of transfer of alkalinity on acidic subsurface soil form lime incorporated into the surface. • Provide information for modelling soil acidification and liming in WA, and extension via AGWEST of knowledge on the optimal rate and efficiency of lime applications.	Dr Andrew Rate (UWA) Mr Mark Whitten (UWA) Ms Teresa Wozniak (UWA)

Understanding sub-soil acidification (UWA3)	• Evaluate the importance of the imbalance of cation-anion uptake by plants in the development of sub-soil acidification.	Dr C. Tang (UWA) and Dr J. W. Bowden (AGWEST)
Sustainable management of soil water and nutrients in the medium rainfall zone of Western Australia (CLIMA/CSIRO)	• Determine the effect of annual and perennial species on drainage, the input, turnover and fate of legume-fixed, 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 heat/grain legume growth models, to test soil water movement models, and to test predictions of lime movement and lime requirements. • To devise pasture/crop rotations for improving efficiency of use of water and nutrients.	Ian Fillery (CSIRO)

Table 5 List of current lime suppliers and contact details in Western Australia

Lime Suppliers	Location	Eastings	Northings	Phone	Fax
Aglime of Australia	Lancelin	342263	6565540	08 9364 4951	08 9316 2917
	Cervantes	316712	6624978	08 9364 4951	08 9316 2917
	Jurien Bay	312057	6652231	08 9364 4951	08 9316 2917
	Dongara	298442	6758761	08 9364 4951	08 9316 2917
Agriburnt Lime	Munster			08 9353 4646	08 9353 3154
Ayres Aglime	Bornholm	553100	6121300	08 9845 1209	08 9845 1061
Beaufort River Dolomite	Beaufort River	504723	6284857	08 9862 5014	08 9862 5014
Creative Land Management	Wanneroo	383100	6492800	08 9330 1207	08 9353 5004
Boranup Limesand	Boranup	319450	6218600	08 9757 2875	-
Bornholm Ag-Lime	Bornholm	551301	6120000	08 9845 1170	08 9845 1314
Breton Bay Limestone	Lancelin	343100	6567350	08 9418 7807	08 9418 7807
Cockburn Cement	Munster	387277	6443266	08 9411 1000	08 9411 1150
Denmark Agricultural Lime	Denmark	563165	6125500	08 9848 1786	08 9848 1786
Dooka Limesand & Gypsum	Dongara	298300	6762400	08 9927 2760	08 9927 2150
Doyle's Lime Service	Myalup	378283	6351667	08 9727 2078	08 9727 2708
Esperance Lime Supply	Esperance	952000	6240800	08 9071 7992	08 9071 7992
Greenhead Sands	Greenhead	307383	6666923	08 9953 1251	08 9953 1251
Irwin Limesands	Dongara	378286	6351667	08 9927 2323	08 9927 1309
Horrocks Limesand	Horrocks Beach	253400	6856700	08 9934 1277	08 9934 1271
Jurien Bay Limesand	Jurien Bay	311530	6646000	08 9652 1272	08 9652 1447
Lake Preston Lime	Lake Preston	376800	6349500	08 9275 3474	08 9725 3475
Lance Lime	Myalup	378450	6336800	08 9720 1002	08 9720 1002
Leeuwin Limestone	Karridale	325000	6213900	08 9758 6711	-

Lime Suppliers	Location	Eastings	Northings	Phone	Fax
Lime Industries	Guilderton	362902	6533439	08 9446 8644	08 9244 2071
	Lancelin	342843	6562189	08 9446 8644	08 9244 2071
	Mandurah	384034	6407452	08 9446 8644	08 9244 2071
	Mingenew	377469	6768968	08 9446 8644	08 9244 2071
	Kwinana	387387	64384600	08 9446 8644	08 9244 2071
	Wanneroo	384196	6494629	08 9446 8644	08 9244 2071
Magenta Minerals	Lake Magenta	709600	6301200	08 9872 0020	-
Marinoni Dolomite	Kojonup	491410	6272387	08 9833 1224	08 9833 1224
Midwest Sand Supplies	Geraldton	263700	6814250	08 9923 1372	08 9923 2227
Nanarup Lime Company	Nanarup	595447	6128930	08 9846 4221	08 9853 2285
K & PM Green	Lake Magenta	710464	6298318	08 9871 1547	08 9871 1690
Pingrup Dolomite	Pingrup	641000	6288600	08 9820 1078	08 9820 1003
Poyner Agricultural Services	Drummonds Cove	266475	6828945	08 9923 3664	08 9923 3440
Redgate Lime	Witchcliffe	316834	6232278	08 9757 6263	08 9757 6071
Rules	Lancelin	343100	6567350	08 9575 2000	08 9575 2112
SuperFert Pty Ltd	Kwinana	-	-	08 9498 0303	08 9498 0303
Versaci Lime	Myalup	378374	6346447	08 9729 1797	08 9729 1797
Watheroo Dolomite	Watheroo	408557	6641685	08 9651 8062	08 9651 8062
Western Agricultural Lime Co.	Manypeaks & Windy Harbour	609598	6137861	08 9776 1206	08 9776 1486
Westlime WA Limited	Dongara	298300	6762400	08 9955 9600	08 9955 9666
Yarra Sands	Coolimba	305288	6698531	08 9951 1064	08 9951 1229

Table 6 Summary of historical scientific papers produced from research conducted in Western Australia on acid soils.

Title	Authors	Publication
Amelioration of subsurface acidity in the south-west of Western Australia: downward movement and mass balance of surface-incorporate lime after 2-15 years	MG Whitten, MTF Wong and AW Rate	Australian Journal of Soil Research 2000. 38: 3, 711-728
Effect of short-term legume residue decomposition on soil acidity	C Tang, G P Sparling, CDA McLay and C Raphael	Australian Journal of Soil Research 1999. 37: 3, 561-573
Effect of lupins and location on soil acidification rates	PJ Dolling	Australian Journal of Experimental Agriculture 1995. 35: 6,753-763
Acidification rates in the central wheatbelt of Western Australia. 1. On a deep yellow sand	PJ Dolling and WM Porter	Australian Journal of Experimental Agriculture 1994. 34:8, 1155-1164
Acidification rates in the central wheatbelt of Western Australia. 2. On a sandy duplex soil.	PJ Dolling, WM Porter and IC Rowland	Australian Journal of Experimental Agriculture 1994. 34:8, 1165-1172
Amelioration of subsurface acidity in sandy soils in low rainfall regions. 1. Responses of wheat and lupins to surface-applied gypsum and lime	CDA McLay, GSP Ritchie, WM Porter and A Cruse	Australian Journal of Soil Research 1994. 32:4, 835-846
Amelioration of subsurface acidity in sandy soils in low rainfall regions. 2. Changes to soil solution composition following the surface application of gypsum and lime	CDA McLay, GSP Ritchie, WM Porter and A Cruse	Australian Journal of Soil Research 1994. 32:4, 847-865
Effects of an acidifying nitrogen fertiliser and lime on soil pH and wheat yields. 1. Soil effects	MG Mason, WM Porter and CJ Cox	Australian Journal of Experimental Agriculture 1994. 32:4, 237-246
Effect of lupins and pasture on soil acidification and fertility	SP Loss, GSP Ritchie and AD Robson	Australian Journal of Experimental Agriculture 1993. 33:4, 457-464
Al toxicity of wheat grown in acidic subsoils in relation to soil solution properties and exchangeable cations	SJ Carr and GSP Ritchie	Australian Journal of Soil Research 1993. 31:5, 583-596
Effect of an acidifying nitrogen fertiliser and lime on soil pH and wheat yields	MG Mason, WM Porter and WJ Cox	Australian Journal of Experimental Agriculture 1994. 34:2,237-246

Title	Authors	Publication
Effect of soil acidity on barley production in the south-west of Western Australia. 1. The interaction between lime and nutrient application	PJ Dolling, WM Porter and AD Robson	Australian Journal of Experimental Agriculture 1991. 31:6, 803-810
Effect of soil acidity on barley production in the south-west of Western Australia. 2. Cereal genotypes and their response to lime.	PJ Dolling, WM Porter and AD Robson	Australian Journal of Experimental Agriculture 1991. 31:6, 811-818
A soil test for aluminium toxicity in acidic subsoils of yellow earths in Western Australia	SJ Carr, GSP Ritchie and WM Porter	Australian Journal of Agricultural Research 1991. 42:5, 875-892
Soil pH and aluminium and their spatial variation in Western Australia	PJ Dolling, WM Porter and AD Robson	Australian Journal of Experimental Agriculture 1990. 30:5, 637-643
Effect of soil acidity and nutrient deficiencies on the growth and persistence of subterranean clover in pastures grown on sandy soils near Esperance, Western Australia	MDA Bolland	Australian Journal of Experimental Agriculture 1985. 25:4, 893-901