THE ECONOMICS OF ACID SOILS

BY

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ABSTRACT

This paper contrasts the economics of managing acid soils (low pH) with and without lime.

A model has been built (Lime-It-2) which simultaneously predicts soil pH increase due to lime, and plant yield response to soil pH for New South Wales. Using these relationships the most profitable liming rate can be determined according to the yield boost it produces.

This paper addresses three questions using the model. First, is it more profitable to simply switch to the acid tolerant plants as the soil acidifies, or should lime be used to maintain the range of plants which can be grown? The answer to this depends on the relative profitability of the acid-soil tolerant crops and pastures and other possible crops and pastures. Using current gross margins and four, ten year rotations typical to the Wagga Wagga area of New South Wales, it was shown to currently be more profitable to lime the soil and grow the plants with the highest gross margins.

Secondly, what is the most profitable pH level in the medium term? This can give an indication of where profit driven farmers will be in the future with regard to their soil pH. If this is the case, then soil pH of profit driven farmers will be between 4.7 and 5.8 for an acid sensitive rotation; and between 4.3 and 4.8 for an acid tolerant rotation. These economically optimum pH levels also depended on the relative profitability of the crops and pastures included in the ten year rotations.

Finally, what is the cost to society in terms of lower farm profits, of the increasing area of soil acidity? An estimate was made for the gross value of production lost from the maximum production level possible for the wheat, barley and oat crops of seven shires in the Wagga Wagga area of New South Wales and five shires in the Rutherglen area of Victoria of $14.7 million and $1.1 million respectively.

If no liming was carried out over the next ten years, the area of acidity did not expand, and the same area of the crops were grown, this cost would increase to $17.3 million for the New South Wales shires and $1.3 million for the Victorian shires. These values represent a worst case scenario for the next ten years.

An estimate was then made of the gross value of production lost which would be economically viable to obtain through liming the soil. This reduced the gross value of production loss estimate to $13.2 million and $0.9 million for the shires surveyed in New South Wales and Victoria respectively. These values were also extrapolated to the 1997/98 production year raising the figures to $15.5 and $1.1 million.

1. INTRODUCTION

A soil with a pH less than 6.5 (in $CaCl_2$) is defined as an acid soil (Bruce, 1988). Soil acidity is associated with toxic levels of aluminium and manganese which cause production losses in plants. However, the soil can be ameliorated with lime to reduce the levels of active aluminium and manganese. Due to the machinery costs, lime is typically only incorporated to plough depth, therefore reversing only the acidity in the topsoil.

Much of the existing soil acidity in Australia developed naturally at a very slow rate. Unfortunately, the agricultural practices over the last 200 years have drastically accelerated this process. Current estimates of the area of soil acidity are around 13 million hectares for New South Wales (NSW) alone (Helyar et.al., 1990). CSIRO estimated 3 million hectares in NSW had induced soil acidity (the soil had not been acid before farming occured), and a further 6 million hectares had the potential to acidify in the future. Further work by CSIRO Division of Soils, has produced detailed pH maps of the area around Wagga Wagga in southern NSW and across the border around Rutherglen in northern Victoria. These provide the opportunity to make more accurate estimates of the production losses in these areas due to soil acidity.

Research work on soil acidity at the NSW Department of Agriculture and Fisheries, Research Institute in Wagga Wagga (NSW Dept.Ag and Fish. A.R.I.) has recently been extended to defining plant growth response to changes in soil pH. This response varies depending on the plant tolerance to aluminium and manganese, and the soil type. (Helyar et.al, 1989). Earlier research by Hochman, Godden and Scott (Hochman et.al. 1989) described the soil pH response to lime, and the subterranean clover response to pH.

Work to date in the economics of soil acidity has largely concentrated on the agricultural side of the problem. Overseas work has been on the integration of plant response to lime curves and the corresponding production value increases. Hall (1983) used soyabean, alfalfa and corn response curves with marginal economic analysis to identify the respective economic lime rates in America. Edmeads (1986) in New Zealand used pasture response curves to lime, in a model to identify the economic returns from liming pasture. In Hawaii, an expert system was developed by Yost et.al. (1988), to determine lime recommendations for soils of the humid tropics, depending on the relative economics involved.

Australian economic research has also followed this line of modelling the plant and economic response to pH. May and Godyn (1985) identified the viability of liming in a cropping phase, using marginal economic analysis. Further work by Hochman, Godyn and Scott (1989) produced a model (called "Lime-It") which also uses marginal analysis to identify the economically optimal lime rate for subterranean clover pastures. Actual estimates of the effects of soil acidification in terms of economic losses to a farm were made by Godyn et.al. (1987) for southern NSW. This was done using linear programming in a whole farm analysis approach for three different pH levels. Godyn identified a net income reduction of around 52% as the pH fell from 5 to 4.6 and negative returns if the pH fell to 4.2.

Two estimates have recently been made of the "cost" of soil acidity. Dr.Helyar at the NSW Dept of Ag.and Fish. A.R.I. at Wagga Wagga, followed on from his estimate of 13 million hectares of soil acidity. By using an average gross margin of $100/ha the potential profit loss was placed at 10% or $10/ha. By extending this figure to the whole state, the cost of soil acidity to NSW was put at $130 million per year. By then doubling this figure the Australian soil acidity profit loss was estimated to be around $300 million dollars. A lower estimate by CSIRO placed the cost of acidification at $100 million dollars (Kelly,1990).

Recent research at the NSW Department of Agriculture Research Station at Wagga Wagga, has following on from the "Lime-It" model of Hochman, Godyn and Scott (1989), to developed an expanded and updated "Lime-It-2" model. This model incorporates marginal economic analysis to determine the optimal economic lime rate for a ten year rotation. This rotation may involve a range of crops and pastures. The plant production data in the model was developed by Helyar et.al.,(1989), while the soil response curves are the from the original "Lime-It" version (Hochman et.al., 1989).

2. METHODOLOGY AND ASSUMPTIONS

2.1 THE LIME-IT-2 MODEL

This model combines factors of the old "Lime-It" model (Hochman et.al.1989) with new research results, to produce an expanded and updated "Lime-It-2" version. The model consists of three sections: (a) the soil responses, (b) the plant responses and (c) the economic responses.

Within the soil response section there are two main calculations. These are: (a) the estimation of the pH change due to lime, and (b) the pH decline over ten years. The soil information required is as follows: soil surface pH (0-10cm); subsurface soil pH (10-30cm); total exchangeable cation content (TEC); soil type group; and region-rotation type group.

The soil type group is chosen from three groups which are determined by the relative aluminium and manganese contents (Appendix A). This factor is used in the plant response section. The region-rotation type group is chosen from nine groups which vary according to the induced soil pH rundown (i.e. farming practices and rainfall; Appendix A). The pH and TEC values are generally provided in results from soil testing.

In the plant response section, only one main calculation is carried out: the relative percentage plant growth possible given the surface and subsurface soil pH (Helyar et.al.,1989). However, within the model there are five tolerance categories into which the crops and pastures are allocated. Each tolerance category also has three curves which relate to the three soil type groups. Thus a response curve is chosen depending on the tolerance category of the plant and the soil type group (Appendix A).

The only plant information required for this section is the ten year rotation of crops and pastures and the climate limited maximum yields possible for the crops and pastures in the rotation. The climate limited maximum yields are defined as the maximum yields possible on the farm given only rainfall and management limitations. These values are in tonnes per hectare of grain for the crops and dry sheep equivalents (dse) stocking rates for the pastures.

The economics section requires information on the crop and pasture gross margins ($/ha and $/dse), the cost of lime, inflation rates for prices paid and prices received and the discount rate. A gross margin base is then determined for each crop/pasture in the ten year rotation for the no lime situation. For a range of lime rates an increase (or decrease) in the net present value of the gross margin over ten years due only to lime, is estimated. This is done using the soil pH change with lime, the soil pH rundown over ten years and the plant production levels given the soils pH. By identifying the lime rate which produces the highest total increase in gross margin, the most economically optimal lime rate can be chosen.

2.2 ECONOMIC ANALYSIS OF LIMING RATES.

To compare the options of not liming and simply growing the more acid soil tolerant plants to liming and growing acid soil sensitive plants, four ten year rotations were chosen and run on the Lime-It-2 model. The net present values of the ten year gross margins for each rotation were then identified. This information was then also used to predict the medium term pH which would occur if all farmers limed to achieve the highest profit.

2.2.1 TEN YEAR ROTATION ASSUMPTIONS

The rotations are representative of enterprise options typical for the south west region of NSW and northern Victoria. They were chosen after consultation with a number of NSW Dept. Ag and Fish. district agronomists, system agronomists and plant pathologists.

Two rotations were chosen as examples of typical farming enterprises for a farm with a soil acidity problem which could be carried out without liming. These involved an all crop rotation of: oats, lupins and triticale; and a crop-pasture rotation using oats, lupins, triticale and undersowing with subterranean clover for years four, five, six and seven.

Two rotations were also chosen for an enterprise which used lime to the economically optimal liming rate. The first was an all crop rotation of wheat, barley, and canola; the second was a crop-pasture rotation with wheat, barley, canola and field peas, undersowing lucerne for years four, five, six and seven.

2.2.2 SOIL ASSUMPTIONS

The soil was assumed to have an initial surface pH of 4.0 and a subsoil pH of 5.0, the T.E.C. was set at 4.5. The soil type group chosen was the "Moderately Weathered" group, and the region-rotation type was set for the "S.W. Slopes, N.E.Victoria - annual pastures and crops"

2.2.3 CROP YIELD AND GROSS MARGIN ASSUMPTIONS

The crops were assumed to have the climate limited maximum yields, prices and gross margins (for the maximum yields) as given in Table 1.

Table 1. **Climate limited maximum crop yields, crop prices and crop gross margins assumed for the analysis.**

CROP	CLIMATE LIMITED MAXIMUM YIELD (t/ha)	CROP PRICE ($/t)	CROP GROSS MARGINS ($/ha)
WHEAT	4.5	145	438
BARLEY	4.5	125	352
CANOLA	2.5	260	340
FIELD PEAS	3.0	200	286
OATS	4.5	120	371
TRITICALE	4.5	125	360
LUPINS	2.0	150	40

2.2.4 PASTURE YIELDS AND GROSS MARGIN ASSUMPTIONS

The two pastures involved were assumed to have the maximum yields, prices and gross margins given in Table 2.

Table 2. **The maximum stocking rates, pasture gross margins, and sowing and maintenance costs assumed for the analysis.**

PASTURE:	SUB.CLOVER	LUCERNE
MAXIMUM STOCKING RATE (dse/ha)	10	14
GROSS MARGINS ($/dse)	30	30
PURCHASE COSTS ($/dse)	30	30
UNDERSOWING COST ($/ha)	35	40
SEPARATE SOWING COST ($/ha)	80	100
PASTURE MAINTENANCE ($/ha/yr)	10	10

2.2.5 LIME COST, INFLATION RATES AND DISCOUNT RATE ASSUMPTIONS

The lime cost carted and spread was assumed to be $76/t, the long term inflation rate for prices paid was 10% per annum, while the long term inflation rate for prices received was 8% per annum. This incorporates a cost price squeeze in the model. The discount rate used was 5% per annum.

2.3 ESTIMATION OF THE GROSS VALUE OF PRODUCTION LOST DUE TO SOIL ACIDITY

To generate an estimate of the "costs" of soil acidity, information on the soil pHs in the Wagga Wagga area of NSW and the Rutherglen area of Victoria, were combined with the estimates of the potential yields of plants in those areas.

Given the surface and subsurface pH estimates for each soil group, the relative percentage yield was estimated for wheat, barley and oats. Using the shire average yield the maximum yield possible for the soil (assuming acidity did not affect plant growth) was calculated as follows:

$$\frac{\text{current yield}}{\text{current \% of maximum yield}} = \text{maximum yield}$$

The difference in yield was then found by subtracting the current yield from the maximum yield for each soil type. This difference was then multiplied by the area of each crop on each soil type and the value of each extra tonne of crop. The final shire loss values are a sum total of the lost potential production for wheat, barley and oats on each soil type within the shire.

To estimate the potential loss in ten years time if no liming was to occur the existing pH was run down over ten years using the soil rundown equations in the Lime-It-2 model. The above methodology was then followed again.

To further make this estimate of the cost of soil acidity more accurate, the difference only between the current yields and the economically optimal yields were calculated. This figure represents the gross value of production lost due to soil acidity, which would be economically viable to obtain with liming.

An economically optimal pH was identified above for an acid soil rotation and a non acid soil rotation, these were between 4.30 and 5.78. The mean of these two values (5.0) was then used as the economically optimal surface pH. The subsurface soil was assumed to have a pH of 5.5 and the TEC was put at 4.5. The gross value of production lost from the economically optimal yield to the production maximum yield was calculated. This figure was then taken from the total gross value of production loss to leave the gross value of production loss which is economic to reclaim using lime. This value was estimated for 1987/88 and 1997/98.

2.3.1 SURVEYED AREAS

Soils were sampled and classified on a 4km grid across two areas partially covering the shires of Coolamon, Junee, Lockhart, Temora, Wagga Wagga, Culcairn and Holbrook in NSW, and Rutherglen, Wangaratta, Yarrawonga, Tungamah and Benalla in Victoria. The soils were allocated to 7 groups on the basis of the Great Soil Groups outlined by Stace et.al.(1967), (Appendix B).

2.3.2 SOIL PH ESTIMATES

Soil pH values for the 0 to 10 cm and 10 to 20 cm layers were determined potentiometrically in a 1 to 5 soil:0.01 M $CaCl_2$ suspension. Means and confidence intervals for the surface and subsurface pH values for each soil group were determined.

2.3.3 ESTIMATES OF AREA OF EACH SOIL TYPE

The areas of each soil group in each shire were generally assumed to be proportional to their frequency of occurence at sample sites, and the proportion of these areas actually used for cropping was assumed to be similar to the frequency of occurence of cropped or croppable land at the sample sites. For example, 68% of the cropped or croppable sites in Coolamon were classified as "earths" therefore it was assumed that 68% of Coolamon wheat was produced on these soils, (Appendix C).

2.3.4 CROP AREA AND AVERAGE YIELD ESTIMATES

The crops used in this study were wheat, barley and oats (all grain only crops). The production areas and production yield estimates for each shire were taken from the Australian Bureau of Statistics for the 1987/88 production year.

The contribution of each soil group to the total shire yields for each crop was relative to the existing pH of each soil group. Thus for the same area of land a soil with a more favourable pH would contribute more to the yield than a soil with a lower pH. This estimation of the relative mean yields for each soil group was determined using the percent of maximum production at which each soil group was currently producing.

2.3.5 GROSS VALUE OF PRODUCTION

The gross value of production was taken from the Bureau of Statistics information and was \$164.81/t for wheat, \$199.61/t for oats and \$131.86/t for barley.

2.3.6 ESTIMATES OF MAXIMUM YIELDS

The plants were assumed to react as defined by the response curves in the Lime-it-2 model, these are detailed below:

1. Oats curve = highly tolerant
2. Wheat curve = tolerant
3. Barley curve = sensitive

The soil type group chosen was the "Moderately Weathered" group and the region-rotation type was set for the "S.W.Slopes and N.E.Victoria - annual pasture and crops".

2.3.7 LIMITATION ON YIELD INCREASES

Due to the fact that some of the surface and subsurface soils pHs represented a situation of no growth, a ceiling was put on the yield increase possible from adding lime. According to Cornish and Murray (1989) the long term potential shire mean for the Wagga area was between 3.7 and 4.4 t/ha for wheat. It has been noted that a large amount (possibly even all) of the yield difference between the current yields of around 2 t/ha and the potential yields of 4 t/ha could be due to the effect of soil acidity (Conyers, pers.com.,1989). To keep estimates conservative, a yield increase of around 1 t/ha was used as the maximum increase possible due to amelioriation of the soil with lime.

2.3.8 SOIL PH RUNDOWN

It was assumed the soil surface pH ran down over the 10 years as defined by the soil equations developed by Hochman, Godyn and Scott (1989). It was also assumed that no liming would occur during the ten years. This represented a worst case scenario.

3. RESULTS AND DISCUSSION

3.1 THE LIME-IT-2 MODEL

This complete model was checked for sensible answers by a number of district agronomists, soil conservation officers and farmers in the southern region of NSW. The results from these model trials were all favourable, indicating that the model was realistic with regard to current soil acidity knowledge.

3.2 ECONOMIC ANALYSIS OF LIMING RATES

3.2.1 IS IT MORE PROFITABLE NOT TO LIME AND GROW ONLY SOIL ACIDITY TOLERANT CROPS AND PASTURES, OR TO LIME AND GROWN ANY CROPS OR PASTURES WANTED ?

The big decision facing a farmer with a soil acidity problem is whether or not to lime. By growing the more acid tolerant plants a farmer with a soil acidity problem can avoid doing anything about the problem for a while and still continue to make a reasonable income.

If this option is chosen then in the long term not only will the soil surface pH run down, but as long as the surface pH is below 6.0 the subsoil will also acidify. Currently, placing lime at depth is inhibitive in cost and difficult to achieve as the existing machinery is not highly effective in distributing the lime throughout the soil. Consequently the farmer will also be acidifying his subsurface soil - an effectively non-reclaimable resource.

From Table 3, the highest gross margins are achieved by liming the soil and growing the acid sensitive crops.

Table 3. **Comparison of two acid tolerant rotations and two acid sensitive rotations, using the Lime-It-2 model.**

	ROTATIONS[1]			
	A1	A2	B1	B2
1. Optimal Lime rate (T/Ha)	2.0	1.5	4.5	5.5
2. Lime rate used (T/Ha)	0	0	4.5	5.5
3. N.P.V. 10 yr G.M. ($/Ha)	3118	3152	4158	4087
4. Lime payback time (years) for lime rate used	0	0	2	5
5. pH for lime rate used	4.0	4.0	5.5	5.8
6. pH ten years after for lime rate used	3.92	3.92	4.7	4.8
7. pH for optimal lime rate	4.8	4.6	5.5	5.8
8. pH ten years after for optimal lime rate	4.4	4.3	4.7	4.8

(1). Rotations were as follows:
YEAR=1 2 3 4 5 6 7 8 9 10
A1=O L T O L T O L T O
A2=O L T SUB.... O L T
B1=W B C W B C W B C W
B2=W W C LUCERNE W W FP
Where O=oats, L=lupins, T=triticale, Sub=subterranean clover pasture, W=wheat, B=barley, C=canola, FP=field peas, Lucerne=Lucerne pasture.

The second highest gross margin was also achieved by liming but included a pasture phase in the rotation. From these results, liming can pay for itself as well as produce the highest profits. It should also be noted that with a higher surface pH the acidification of the subsurface soil will be slower, and therefore preserve the production capacity of the subsurface soil pH for longer.

The final results depended mainly on the relative gross margins for the crops and pastures. With an acid soil the flexibility in crop choice is decreased, therefore crop price differences cannot be taken advantage of. For example, to include a crop legume in an acidified soil the farmer is limited to lupins. This year (1989/90) the price of lupins is at a low of $150/tonne which reduces the gross margin for a typical farming enterprise in the Wagga Wagga area to under $50/ha. Note that this gross margin does not value the nitrogen added to the soil, and the value of grazing livestock on the stubble.

3.2.2 WHAT IS THE MOST PROFITABLE PH LEVEL IN THE MEDIUM TERM ?

This pH value depends on the crops or pastures being grown and their respective gross margins. The higher the gross margins, the higher the returns from raising the pH. Also the more acid sensitive the plant, the higher the marginal returns from raising the pH.

If liming to the most profitable level in the medium term (ten years) is encouraged, profit driven farmers will push the surface soil pH to between 5.5 and 4.7.

The environmentally driven farmers would push the surface to at or above 6.0 to halt and possibly reverse the subsurface soil acidification.

3.3 ESTIMATION OF THE GROSS VALUE OF PRODUCTION LOST DUE TO SOIL ACIDITY.

By combining the soil survey results from CSIRO Division of Soils and the Lime-It-2 model, estimates of the gross value of production lost in the 1987/88 were made in this paper (Table 4). The cost of soil acidity for the wheat, barley and oats crops in the Wagga Wagga area of NSW was placed at around $14.9 million. For the five shires surveyed in Victoria, this figure was around $1 million.

To identify how serious the soil acidity problem could become, the soil pH identified for each soil type in the survey were degraded according to the pH decline equations in the Lime-It-2 model (Table 5). This showed that in the next ten years, if no liming was to occur the soil acidity problem could grow to a $17.3 million cost.

A more conservative estimate of the cost of soil acidity was identified by calculating the relative production level for the economic surface pH of 5.0. This reduced the cost estimate (Table 6). The 1987/88 gross value of production lost for the Wagga Wagga area was $13.2 million and for the Rutherglen area was $0.9 million. This estimation was also made for the cost in ten years time (Table 7), and estimated the soil acidity costs at $15.5

and $1.1 million for the Wagga Wagga and Rutherglen areas respectively.

Table 4. Gross value of production lost in the wheat, barley and oat crops due to soil acidity for the 1987/88 production year in seven shires in the Wagga Wagga area of N.S.W. and five shires in the Rutherglen area of Victoria.

CROPS	WAGGA WAGGA AREA OF N.S.W. ($)	RUTHERGLEN AREA OF VICTORIA ($)
WHEAT	7,998,298	835,506
BARLEY	5,667,902	68,174
OATS	1,242,053	188,189
TOTAL	14,897,253	1,091,869

Table 5. Gross Value of production lost in the wheat, barley and oat crops due to soil acidity for the 1997/98 production year in seven shires in the Wagga Wagga area of N.S.W. and five shires in the Rutherglen area of Victoria.

CROPS	WAGGA WAGGA AREA OF N.S.W. ($)	RUTHERGLEN AREA OF VICTORIA ($)
WHEAT	9,997,996	990,562
BARLEY	5,642,623	82,073
OATS	1,604,352	188,189
TOTAL	17,244,971	1,260,824

Table 6. Gross value of economic production lost (production which is economical to retrive by liming), for the wheat, barley and oat crops due to soil acidity for the 1987/88 production year in seven shires in the Wagga Wagga area of N.S.W. and five shires in the Rutherglen area of Victoria.

CROPS	WAGGA WAGGA AREA OF N.S.W. ($)	RUTHERGLEN AREA OF VICTORIA ($)
WHEAT	7,015,497	675,686
BARLEY	5,015,231	52,245
OATS	1,151,813	170,213
TOTAL	13,182,541	898,144

Table 7. Gross value of economic production lost (production which is economical to retrieve by liming) for the wheat, barley and oats crop due to soil acidity for the 1997/98 production year in seven shires in the Wagga Wagga area of N.S.W. and in five shires in the Rutherglen area of Victoria.

CROPS	WAGGA WAGGA AREA OF N.S.W. ($)	RUTHERGLEN AREA OF VICTORIA ($)
WHEAT	9,025,195	830,742
BARLEY	4,989,952	66,144
OATS	1,515,112	170,213
TOTAL	15,530,259	1,067,099

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APPENDIX A.

1. SOIL TYPE GROUPS USED IN THE LIME-IT-2 MODEL.

Mild Group (Mildly weathered)	- Red, black and red-brown earths - Massive and cracking clay soils - Prairie soils - Chocolate soils
Moderate Group (Moderately weathered)	- Podzolis: 3 Earths - Solodics
High Group (Highly weathered)	- Podzolics - Acid sands - Krasnozems

2. REGION-ROTATION TYPE DIVISIONS.

A. S.W. Slopes, N.E. Victoria - annual pasture/crop
B. S.W. Slopes, > 500mm - crop/crop
C. Tablelands, > 25% crop/annual pasture
D. Tablelands, > 25% crop/perrenial pastures
E. Tablelands, annual pastures
F. Tablelands, perennial pastures
G. Plains, < 500 mm, crop/crop
H. Plains, < 500 mm, crop pasture
I. Irrigation + N, high rainfall areas, crop/pasture

3. TOLERANCE CATEGORIES.

1. Highly tolerant
2. Tolerant
3. Sensitive
4. Highly sensitive
5. Lucerne

4. CROPS AND PASTURES AVAILABLE IN THE LIME-IT-2 MODEL.

1. Tolerant wheats
2. Sensitive wheats
3. Tolerant triticales
4. Highly tolerant triticales
5. Oats
6. Canola
7. Barley
8. Highly tolerant lupins
9. Tolerant lupins
10. Field peas
11. Chick peas
12. Subclover - undersown
13. Subclover - sown separately
14. Lucerne - undersown
15. Lucerne - sown separately

APPENDIX B.

1. AREAS SURVEYED.

NSW	- Coolamon	*Victoria*	- Rutherglen
	- Junee		- Wangaratta
	- Lockhart		- Yarrawonga
	- Temora		- Tungamah
	- Wagga Wagga		- Benalla
	- Culcairn		
	- Holbrook		

2.1 SOIL PH VALUES FOR THE GROUP DIVISIONS SURVEYED IN NSW.

	MEAN	
	surface	subsurface
1. Clay	6.43 ± 2.52	6.85 ± 2.46
2. Red-brown earth	4.96 ± 0.24	5.73 ± 0.30
3. Non-calcic brown soil	4.09 ± 0.26	4.75 ± 0.45
4. Podzolic earth	4.72 ± 0.08	5.15 ± 0.11
5. Solodic	4.60 ± 0.18	4.84 ± 0.20
6. Podzolic	4.54 ± 0.26	5.28 ± 0.38
7. Earths	4.38 ± 0.08	4.58 ± 0.09

2.2 SOIL PH VALUES FOR THE GROUP DIVISIONS SURVEYED IN VICTORIA.

	MEAN	
	surface	subsurface
1. Clay	5.03 ± 0.32	6.11 ± 0.38
2. Red-brown earth	4.80 ± 0.11	5.72 ± 0.33
3. Non-calcic brown soil	4.73 ± 0.18	5.03 ± 0.47
4. Podzolic earth	4.59 ± 0.21	4.91 ± 0.35
5. Solodic	4.50 ± 0.17	4.92 ± 0.40
6. Podzolic	4.37 ± 0.32	4.48 ± 0.29
7. Earths	-	-

3. SURFACE SOIL PH AFTER TEN YEARS.

	MEAN	
	NSW	Victoria
1. Clay	6.19 ± 2.37	4.87 ± 0.30
2. Red-brown earth	4.81 ± 0.23	4.66 ± 0.11
3. Non-calcic brown soil	3.99 ± 0.24	4.59 ± 0.17
4. Podzolic earth	4.58 ± 0.07	4.46 ± 0.20
5. Solodic	4.47 ± 0.17	4.38 ± 0.16
6. Podzolic	4.41 ± 0.24	4.25 ± 0.30
7. Earths	4.26 ± 0.07	-

Note: The subsurface soil pH was held fixed as this generally acidifies over a much longer time scale (K. Helyar, *pers.comm.*, 1989).

APPENDIX C

1. AREAS OF CROP AND SOIL TYPE IN EACH SHIRE, NSW.

	Coolamon	Junee	Lockhart	Temora	Wagga	Culcairn	Holbrook
Wheat	48540	25000	36705	43863	31243	18722	452
Barley	15809	4607	15017	7351	11417	3641	0
Oats	10289	10137	16852	12599	17178	14012	3534
Total	74638	39744	68574	63813	59838	36375	3986
1. CLAY	971	397	0	0	1197	0	0
2. RBE	4854	2385	27429	6381	2992	10912	0
3. NCBS	971	3974	0	11487	0	727	0
4. PODE	3883	9936	13715	1276	5984	0	398
5. SOLD	0	0	3429	0	1795	6547	1196
6. PODZ	4854	7949	20572	0	22140	18189	2392
7. EARTH	33007	15103	3429	44669	25730	0	0
TOTAL	48540	39744	68574	63813	59838	36375	3986

2. AREAS OF CROP AND SOIL TYPE IN EACH SHIRE, VICTORIA.

	Rutherglen	Wangaratta	Yarrawonga	Tungamah	Benalla
Wheat	3600	3300	7900	13000	6800
Barley	0	0	300	1400	0
Oats	1600	2800	2600	4500	4100
Total	5200	6100	10800	18900	10900
1. CLAY	832	1046	491	3835	1677
2. RBE	0	0	3927	10135	1397
3. NCBS	832	697	3436	2739	2795
4. PODE	3120	2963	0	0	559
5. SOLD	416	348	1964	1643	1118
6. PODZ	0	1046	982	548	3354
TOTAL	5200	6100	10800	18900	10900