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The economics of land degradation

The case of acid soils*

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A dynamic optimisation model is constructed to assess the response of farmers to acid soils. It is based on technical coefficients from the Lime-It model, developed by the Wagga Wagga Research Station of the New South Wales Department of Agriculture and Fisheries. The model is of sheep production in the Wagga Wagga district of New South Wales. The objective function is to maximise the net present value of annual profits over 40 years.

For the soil and enterprise conditions modelled, it was found that farmers treated their land as a renewable rather than a depletable resource. Therefore it is profitable to lime soils so that productivity does not fall below a certain level. The level depends on input and output prices. If output prices are high, it pays producers to reduce acidity more. Also, high long term interest rates lead to less remedial action and greater acidification. It is concluded that acid soils are a private problem to be addressed by farmers. Government's role should be to promote the development and extension of appropriate information.

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Introduction

High soil acidity is reducing the yield of some of the more productive agricultural land in Australia. The area known to be affected by reduced yields has increased, particularly since the mid-1970s, and further areas are expected to be progressively affected.

Much of the area affected was among the first to be planted to subterranean clover before or shortly after the Second World War. Under improved pasture, soil acidity can rise progressively as a result of the enhanced nitrogen status of the soil, particularly if artificial fertilisers are used. As soil acidity continues to rise, problems of reduced yield can be expected to emerge in areas more recently planted to improved pastures.

Soil acidity can be controlled through using lime, changing management practices or some combination of both. This raises the question — if acidity can be controlled, why has the problem of reduced yield arisen? There is some evidence to suggest that, until relatively recently, farmers did not know that their management practices could result in acid soil. This evidence, combined with broad public concern about land degradation, led to the establishment of government programs in most states to provide a greater level of information for farmers on the causes, effects and ways of reducing yield losses arising from high soil acidity. However, another reason for increased acidity may be that applying lime can be expensive and such a practice may not be profitable for farmers in all instances.

In this paper, a dynamic profit maximising farm model has been constructed in order to assess what the effect might be of providing farmers with full information on the causes and effects of soil acidification. The model is of sheep production in the Wagga Wagga district of New South Wales. The objective function of the model is to maximise the net present value of a stream of annual profits over 40 years.

Causes of soil acidification

The purpose in this section is to outline some aspects of the causes of acid soils, effects on yields and some of the management practices that can be used for remedial action. This background information will be important later in the paper in setting the context for the dynamic optimisation model.

The soil acidification process and effects

A full description of the chemical processes involved in soil acidification is beyond the scope of this paper and can be found in the scientific literature (for example, Williams 1981; Helyar 1987).

The acidity or alkalinity of soils varies widely among soil types and among regions.[1] Some soils are naturally acidic. However, depending on the system of farming, soil type and climate, agricultural activities may increase soil acidity. The growing of nitrogen fixing legumes and application of artificial fertilisers are the principal management practices contributing to the soil acidification process. Another land management practice which has contributed to increased soil acidity is the removal of acid neutralising carbon, for example by taking hay or wool, from paddocks. This interrupts the carbon cycle and is an important contributor to acidification of soils under pasture (Ridley, Slattery, Helyar and Cowling 1990).

Many of the farms that now have problems with acid soils are in areas where mixed cropping and livestock farms are common. In the mixed farming areas of southern Australia, about 60 per cent of soil acidification can be attributed to nitrate leaching (Ecologically Sustainable Working Group 1991). Under subterranean clover pastures, reduced plant yields resulting from acid soil may occur after twenty to fifty years (Cregan and Helyar 1986). The major cause of acid soil is the buildup of nitrates in the upper soil layers. This is a result of the normal farming systems used in areas where acid soils have become a problem.

Since the Second World War, there has been extensive growing of improved pastures over wide areas of agricultural land in Australia. The so called 'super-sub' revolution, whereby native pastures were replaced by subclover dominant pastures fertilised with superphosphate, has been an important contributor to acidity. Acidity was first recognised to be an agronomic problem in areas where these pastures have been grown for thirty years or more. Areas of highest induced acidity are areas where pastures improved with shallower rooted subterranean clover are common. These tend to be in the higher rainfall areas (Cregan and Helyar 1986).

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[1] Acidity is measured by a value on a scale of 1–14 known as the pH scale. Soils with a pH value of less than 5.6 are commonly classified as acidic and yields of most plants begin to decline when soil pH drops below 5.0. The effect of different pH levels on yield varies widely, not only with plant type, but soil type and climatic conditions. Therefore, a low pH level in one area may not necessarily indicate that plant yields are depressed.

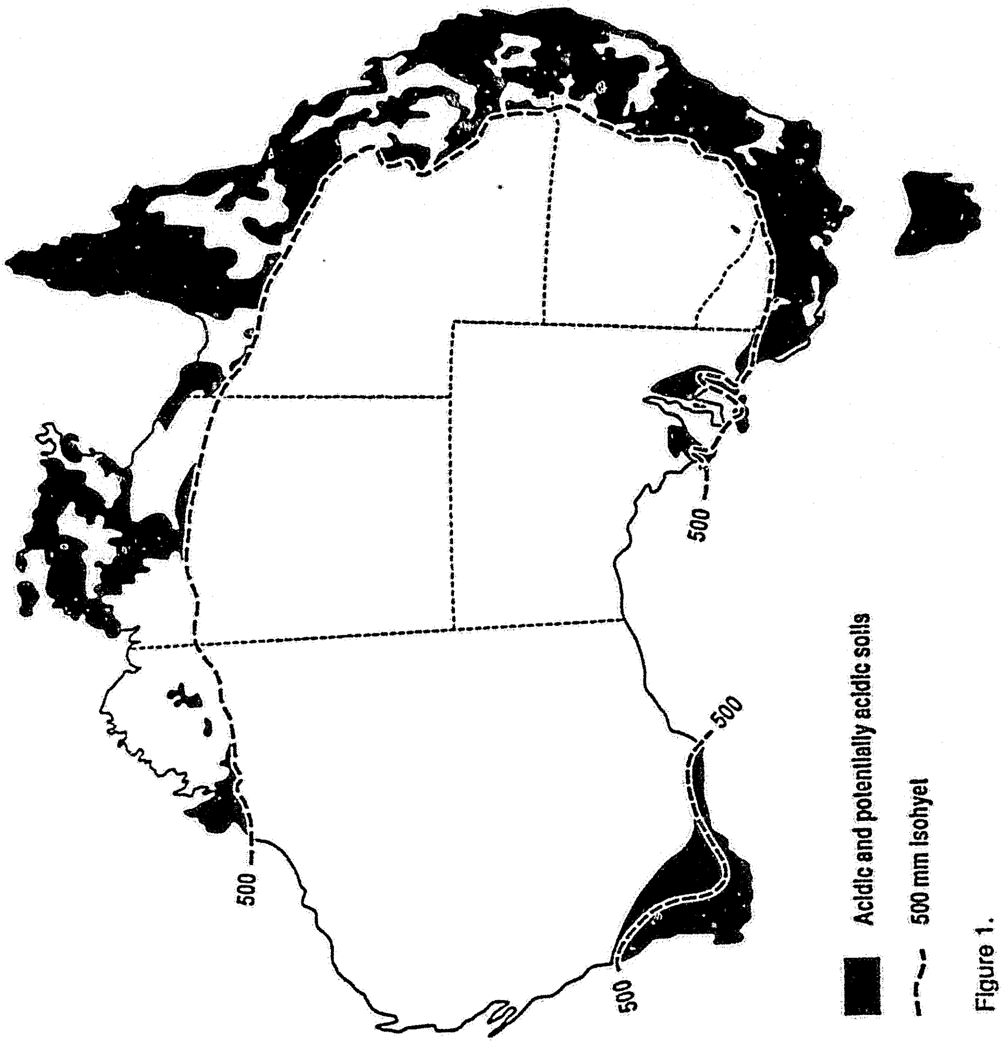
High soil acidity affects plant yields in various ways, one of which is through toxic effects of naturally occurring elements in the soil. For example, as soil acidity increases, aluminium and manganese become more readily available to plants and at high levels are toxic to plants. Conversely, other elements, such as molybdenum which is vital to plant nutrition, may become less available to plants (Cregan 1981). Hence, the effect of changes in pH on plant yields depends in part on the chemical composition of soils and can vary widely from soil to soil. However, there is a general pattern of effects of pH on plant yields. Yields are generally unaffected by pH over the range of neutral to acid soil (pH 7.0–5.6). As pH declines below 5.6, yields fall sharply reaching a very low level for most crops at around 4.0. For example, wheat yields in the Wagga Wagga area in New South Wales are reported to decline by 12 per cent between pH 5.0 and pH 4.6 and to decline by a further 29 percentage points between pH 4.6 and pH 4.2 (Godyn, Cregan, Scott, Helyar and Hochman 1987).

The geographical incidence of acid soils is not known with great precision. The estimated area of agricultural land in Australia where soils are acid or where soils are at risk of acidity is about 25 million hectares (Ecologically Sustainable Working Group 1991). The area of land where yields have been reduced as a result of highly acid soils could be much less. As noted above, the effect of soil acidity on yield may differ depending on soil type and local farming systems. There are still many areas where acidity is not widespread but which have the potential to become so. Areas that are prone to induced or natural soil acidity are shown on the accompanying map.

Treatment of acid soils

There are several actions that farmers can take in response to the agronomic problems caused by soil acidity. These include changing their enterprise mix to more acid tolerant plants, adopting farm management practices which slow the acidification process and applying lime to lower the acidity of the soil.

Some broadacre crops are more tolerant of high soil acidity than other crops (table 1). Oats, for example, are more tolerant of acid soil than barley. Farmers may accommodate increased soil acidity by growing more of the crops that are less effected by such problems. It is also possible that the land could be taken out of broadacre production for other uses, for example, agro–forestry. However, by reducing the range of crops that can be grown, soil acidity may reduce the flexibility that farmers have to respond to changing relative commodity prices.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■ Acidic and potentially acidic soils
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Figure 1.

Table 1: Effect of soil pH on plant yields in Wagga Wagga, New South Wales a

pH	Oats–triticale	Wheat	Barley–rape	Subclover–pasture
	% yield	% yield	% yield	% yield
5.0	100	100	100	100
4.6	92	88	73	92
4.2	74	59	27	78

a Based on moderately responsive soil.
Source: Godyn, Cregan, Scott, Helyar and Hochman (1987).

Cregan and Helyar (1986) have identified several management practices that can be used to reduce, slow down, or even halt, the soil acidification process. These practices include feeding hay out in the paddock from which it was cut in order not to interrupt the carbon cycle, incorporating cereal straw into the soil, timing plantings to minimise nitrogen leaching and using plant types that use more nitrogen from the soil. However, there may be increased cost if new equipment is needed or increased managerial input is required, and it may, therefore, not always be of net benefit for farmers to change management practices.

Lime neutralises the acidity in the soil, thus raising the pH value (Cregan 1980; Helyar 1987). Broadly, the effect of lime on soil pH diminishes as pH increases but the effects vary widely from site to site. Factors which influence the effect of lime are the buffering capacity of the soil and rainfall. Moreover, the effect of lime differs over time, reaching a maximum some time after application and then declining progressively. Usually lime is spread out on the soil surface and can be incorporated through cultivation or the effect of rainfall. Field studies show that lime leaches into the soil over three to four years in high rainfall areas (greater than 600 mm a year). In drier areas, the rate of movement is much slower (Helyar 1987). In these drier areas or on sites with high subsoil acidity, lime can be incorporated through deep ripping, but this is more costly than surface application.

Economic considerations for acid soils

Optimal remedial measures for acid soils

It is often assumed that degraded land should be returned to its original condition where possible. This assumption is illustrated in some of the estimates of cost of land degradation which base their measures on total repair of degraded land (Blyth and McCallum 1987). In the case of acid soils, this may be achieved by applying lime to return soil to its original lower level of acidity. However, lime is not costless and the private benefits gained by the farmer may not match the cost of purchasing and applying lime. Depending on the relative benefits and costs, a farmer may not find it profitable to apply lime at all or, at the other extreme, it may be profitable to raise the pH of the soil above its original level.

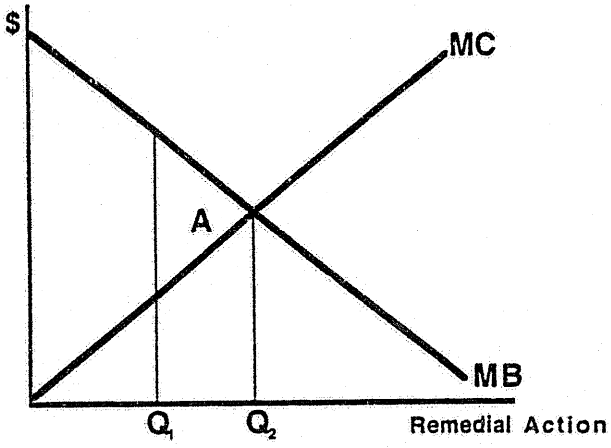
The key factors that determine whether it is optimal to deplete soil or to maintain it are the financial discount rate and the rate of growth in the value of soil. The rate of growth in the value of the soil depends on the stream of benefits that can be derived from the soil. In general, if the rate of growth in the value of a resource, such as soil, is slower than the financial discount rate, then it would be optimal to deplete the resource (Fisher 1981). The economic criterion used to justify depletion applies when the increase in the value of output resulting from remedial measures, such as liming, is less than the cost of the measures. In this case, it would be more profitable to deplete the resource — that is, the soil — and invest the profits in another investment receiving the financial discount rate than it would be to invest in maintaining soil fertility. On the other hand, if the rate of growth in the value of soil exceeded the discount rate, then it would be optimal to conserve the soil. If it was profitable for farmers to conserve their soils, then there would be some optimal soil condition consistent with maximum long term profitability. It may well be that the optimal condition of the resource stock would be of a lower or higher pH status than the original status.

The economic concepts discussed above can be illustrated using the model outlined in Blyth and McCallum 1987 (figure 1). The curve, MB, is the marginal benefit curve and represents the marginal returns to agriculture associated with each level of remedial action. The curve, MC, represents the marginal cost of remedial action. This is the least cost remedial action. The optimal, profit maximising point is where marginal cost and marginal benefit are equal. This occurs at Q_2 in figure 1. If there is some form of market failure, such as lack of efficient information, then the level of remedial action may be less than optimal. This could be depicted as Q_1 in figure 1. If remedial action is at this level, then the net benefit forgone by society from degradation is depicted by area A.

Possible market failure

Two possible sources of market failure relevant to the issue of acid soils are the non-excludability characteristics of information, leading to inadequate supply of information, and the lack of markets to overcome any divergence of preferences for the level of land degradation that might exist between farmers and other members of society.

Figure 1: Optimal remedial action



Optimal soil acidity might be reached if there were perfect information about the causes of acid soil, the techniques that could be used to lower soil acidity and the relevant costs and benefits of such action. However, in practice, there may be deficient information and farmers may, for example, only manage the soil so that soil acidity equivalent to Q_1 occurs. As previously indicated, this would result in an economic cost to society (depicted as area A in the diagram). There is some evidence that, until relatively recently, farmers did not have the information they required to know that their management practices were making their soil acidic. Scientific papers pointing to the problem of acid soils were published during the late 1950s and early 1960s (for example, Williams and Donald 1957). However, there was not widespread use of lime until the acid soil problem became evident in the late 1970s and early 1980s and when events such as the Riverina Outlook Conference in 1981 began to draw the attention of farmers to the reduced yields their farm practices were creating, and which were then becoming evident.

Even if farmers had perfect information on the effects of their farming practices on future yields, farmers' private preferences and attitudes to risk may result in the overuse of soil resources from the point of view of the rest of society. It has been argued, for example by Sinden (1988) and Chisholm (1987, 1988), that land degradation affects the welfare of non-farm members of society who value undegraded land. People other than farmers may wish to maintain soil in an undegraded state because they value the existence of undegraded soil or the option of using undegraded soil in the future. However, it is often difficult to establish markets for these values because of the difficulty of identifying the parties and the number of people involved (Wills 1987). This makes it difficult to determine the existence value of soil that is not acidified. There is no evidence to suggest that the existence value for unacidified soil is large.

The importance of any divergence between private and social returns may be greater where soil acidification is irreversible. Field studies in north-eastern Victoria have revealed soils which are strongly acid deep into the subsoil, and which show no response to liming (Helyar, Hochman and Brennan 1988). Apart from replacing the soil, it may no longer be possible to return these soils to their pre-acidity state. That is, soil acidity has, given current economic settings and technology, become irreversible and without some technological innovation some potentially valuable future use of the soil may have been lost.

The major current loss is farming income. There may be some loss of non-agricultural production alternatives, such as agro–forestry. But the economic effects of soil acidity appear to be largely site specific so that the costs would be borne by the land owners and, if known about, would be reflected in the owners' land management decisions. Hence, the economic issue would appear to be the farmers' lack of information on the effect of soil acidity, both on crop yields and on loss of future alternative land uses.

Dynamic model of liming

Maintaining optimal soil productivity

A model of the technical relationship between lime application, soil pH and crop and pasture yields has been developed and is in use as a farm management advisory tool by New South Wales Agriculture (Fraser and Geeves 1990). This model, the Lime-It model, is nonlinear and can be used be used to estimate the effect of lime applications on broadacre crop and livestock production over an extended time horizon for a wide range of soil types and conditions. In this paper, the Lime-It model has been extended to include a behavioural model of farmers decision making. The behavioural model is broadly that a farmer acts to maximise the net present value of profits over forty years. This period was selected because lime can have effects on yields over a very long time period.

The model can be used to investigate the behaviour of farmers in response to changes in output prices, the price of lime, the cost of spreading lime or changes in the long term real interest rate faced by farmers. The cost of applying lime has two components in the model, a fixed component equal to the costs per hectare of spreading lime and a variable component set equal to the lime price per tonne. Farmers may choose to avoid the fixed component by applying lime only in some years and allow the pH status of the soil to decline in between applications. The technical specification of the model is outlined in the appendix.

Briefly, the pH status of soil is modelled to follow a declining path in the absence of liming. This reflects the process of soil acidification under a regime based on subterranean clover. In the model, farmers are assumed to apply lime to their soil so as to maximise the net present value of the stream of profits derived from the crops grown or livestock raised. As the effects of liming are complex, a model has been developed using the technical relationships established in the above studies. These relationships are nonlinear so nonlinear programming techniques are required.

For any experiment, the model is specified for a particular crop or livestock industry in a nominated region. In this paper, the model specification is based on improved pastures in the Wagga Wagga area. This region has a significant acid soils problem and is broadly representative of agricultural systems being affected by increasing soil acidity in Australia. The technical coefficients used in the model are obtained from earlier studies of the process of soil acidification (Hochman, Godyn and Scott 1989; Fraser and Geeves 1990).

The formulation of the model simulates how farmers respond to increasing acidification by either taking remedial action or continuing to run down soil quality. There may be some parameter values which would lead to the optimal action by farmers being to run down their soil. High lime prices, low output prices, high rates of discount and high acidification rates would make it more likely that farmers would find it optimal to run down their soil.

Farmers' response to soil acidity

The model can be used to describe the optimal response of farmers when they discover that soil acidification is occurring. Figure 2 shows the optimal path of lime application and soil pH for base values of output and lime prices (see appendix). In this initial scenario, it is assumed that all of the costs of applying lime are variable costs, that is, the fixed application costs are added pro rata to the variable costs. This assumption allows the optimal path to be more easily demonstrated. The optimal path has lime being applied every year and pH increasing to a level that is maintained by small annual applications. Under these base assumptions, it would not be optimal to correct the soil acidity problem all in one year because lime in the soil is lost at a higher rate for higher lime applications than for low applications and the relationship between yield and pH is nonlinear.

Figure 2: Optimal soil pH and liming rates

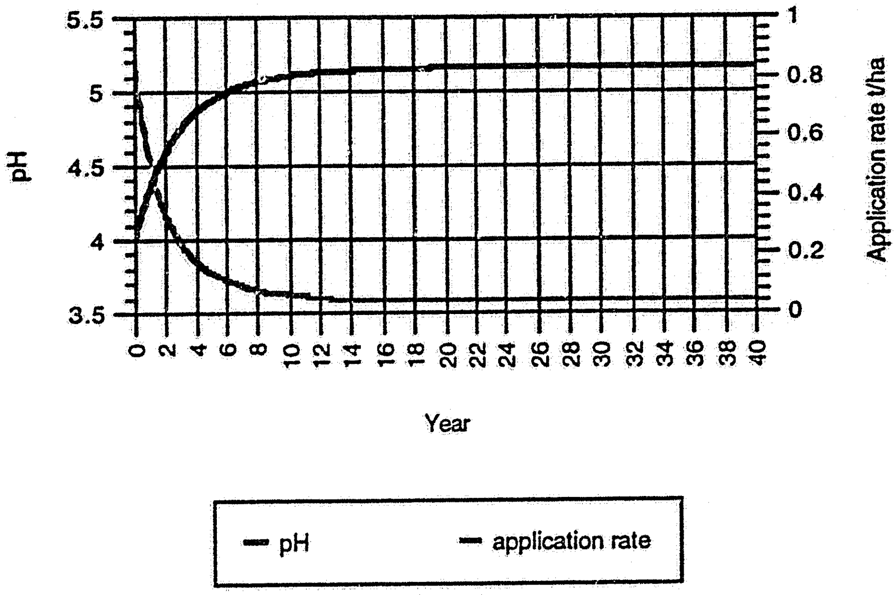
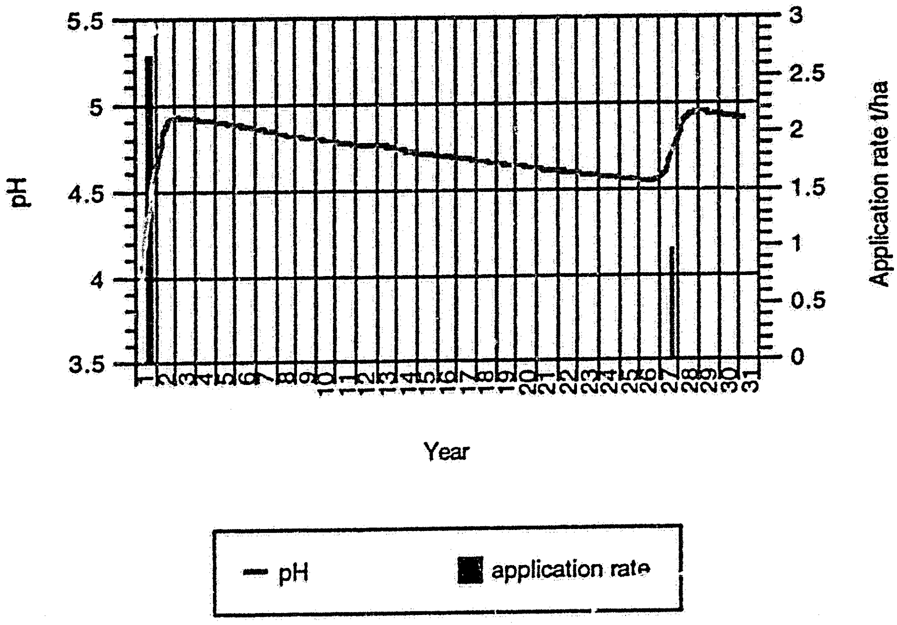


Figure 3: Optimal pH and liming rates when liming has a fixed cost



In practice, there are overhead costs to spreading lime which do not vary with the rate of application. Figure 3 shows that the optimal pattern of lime application, where a certain part of the overall costs are overhead costs, is quite different when all costs are variable with the rate of application. Now it becomes optimal to apply a considerably greater quantity of lime in the initial year to boost soil pH, and then to let pH gradually decline for a couple of decades before further remedial applications are made. (These results would need to be modified if excessive lime applications were detrimental to particular aspects of soil fertility, see Uren 1990.) The exact timing of later applications made only a small difference to discounted profit streams. For example, making applications at year 20 or 30 instead of the estimated optimum in year 28 led to only very small decreases in the net present value of profits. It would appear, therefore, that the precise timing of further lime applications is not critical to profit performance. This result means that farmers could time their lime applications to coincide with high income years when, because of the progressive structure of tax rates, their cost of capital expenditure would be lowest (Lewis, Hall, Savage and Kingston 1988).

The optimal long run pH does not depend upon the initial pH of the soil, but rather on the economics of achieving various pH levels. These results are illustrated in figure 4 where the effect of different initial acidity levels are examined. The fixed costs of applying lime were not separately included for the estimations in this or subsequent figures so that the movement of pH toward the optimum could be illustrated more readily. (The inclusion of fixed costs of lime spreading leads to a cycle in soil pH without a terminal pH being revealed.) The optimal pH depends on, among other things, the price of lime, the output price and the discount rate. In figure 5, the effect on the optimal pH level of varying the lime price is illustrated for base values of the model. As lime prices increase, it becomes less economic to apply lime and the optimal pH is lower.

Inefficient information cost

The model can also be used to measure the costs of inadequate information about the occurrence of soil acidification and of management responses. Consider the situation where a soil has a pH of 4.2. When the problem is identified, a profit maximising farmer could undertake remedial action. The difference between the discounted profit streams with and without remedial action represents the net present value of insufficient information to farmers that acidification is occurring which could be avoided through liming. This benefit, as shown by area A in figure 1, represents the cost of inadequate information available to a farmer in such circumstances.

Figure 4: Optimal path of soil pH for different initial pH values

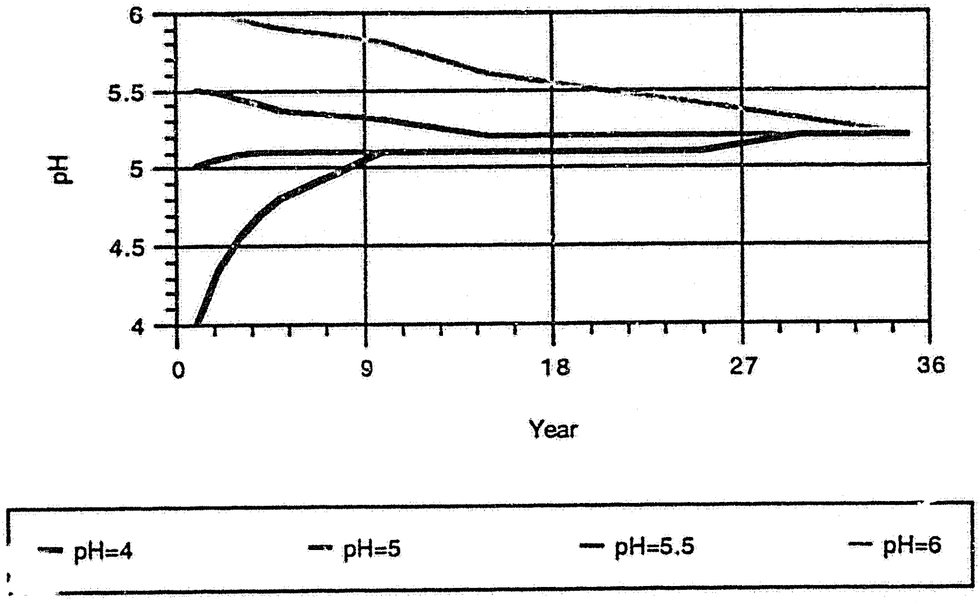
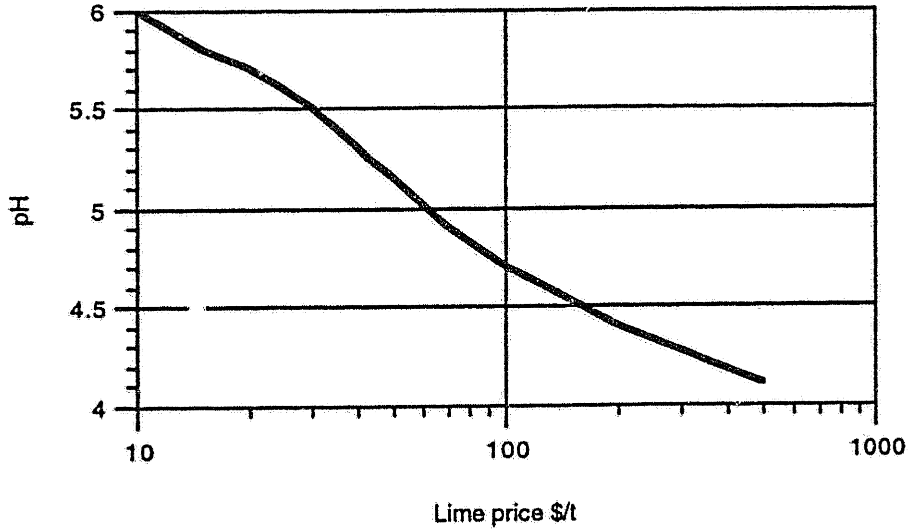


Figure 5: Optimal pH and the price of lime



Using base values, the difference in the discounted value of the gross margins between returning soil to a pH of 5.15 (the pH value which is maintained) and soil with a pH of 4.2 is $125/ha. At the real discount rate of 5 per cent (which was used in the calculation), this cost is equivalent to a stream of annual costs of $6.25/ha.

Demand for lime

The model can be used to estimate the effect of the price of lime on the optimal pH of soil. The estimated demand for lime is shown in figure 6. At the base price of lime, $43/t, the elasticity of demand is 0.6. The demand estimates are of derived demand over the first five years of application. Note that this elasticity depends, among other things, on output prices, discount rates and the pH status of the soil. Because the model does not take account of farmers' ability to change production mix in response to acidification, the estimated elasticity of demand represents a lower bound estimate and is lower than it would be if farmers were able to change output mix. At a future time, if farmers had corrected their acidity problem and only used prophylactic applications of lime, then the demand elasticities could be different.

Effect of different real discount rates on soil pH

The model is constructed so that the impact of changes in discount rates can be investigated. High real discount rates would increase the optimal soil acidity and would reduce the optimal rate of adjustment in soil acidity. If the discount rate was high enough, the optimal soil pH would be lower. Figure 7 illustrates the effect of different real discount rates on optimal soil acidity for base parameters of the model. It also shows the optimal amount of lime to apply over the first five years.

From the figure, it is clear that high discount rates lead to lower lime applications and a lower soil pH. However, even if the real discount rate was as high as 10 per cent, it would still be optimal to conserve soil rather than run it down to a point where it became unproductive, but the optimal pH would be at a lower level.

Effect of varying the output price

There has been some debate about the effect on land degradation of increasing output prices. Some argue that higher output prices would encourage a more intensive use of soil so that its quality would be run down (for example, La France 1990a,b; McConnell 1983). On the

Figure 6: Demand for lime

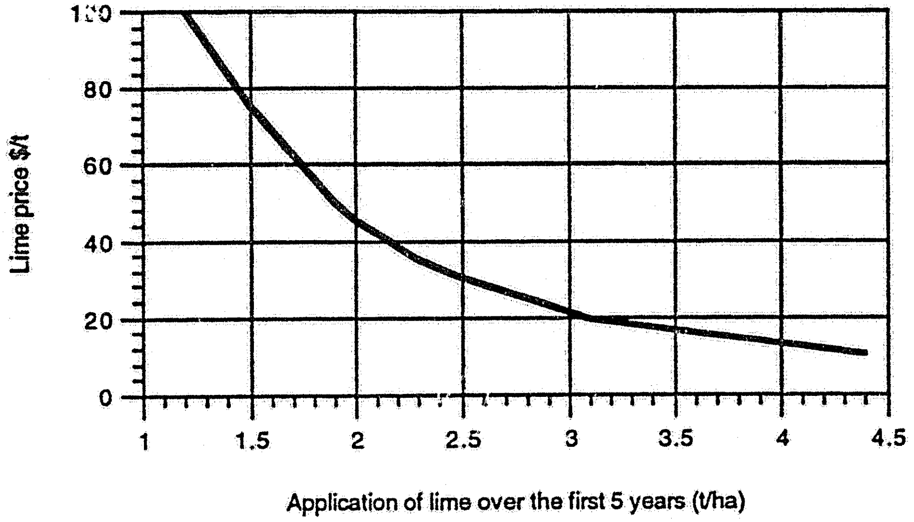
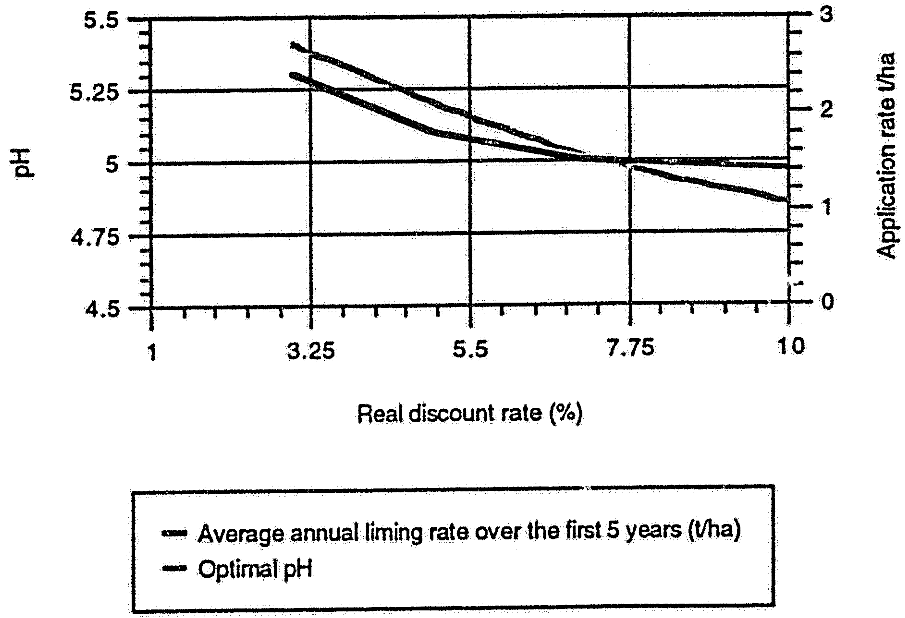


Figure 7: Effect of changing interest rates on liming rate and optimal pH levels

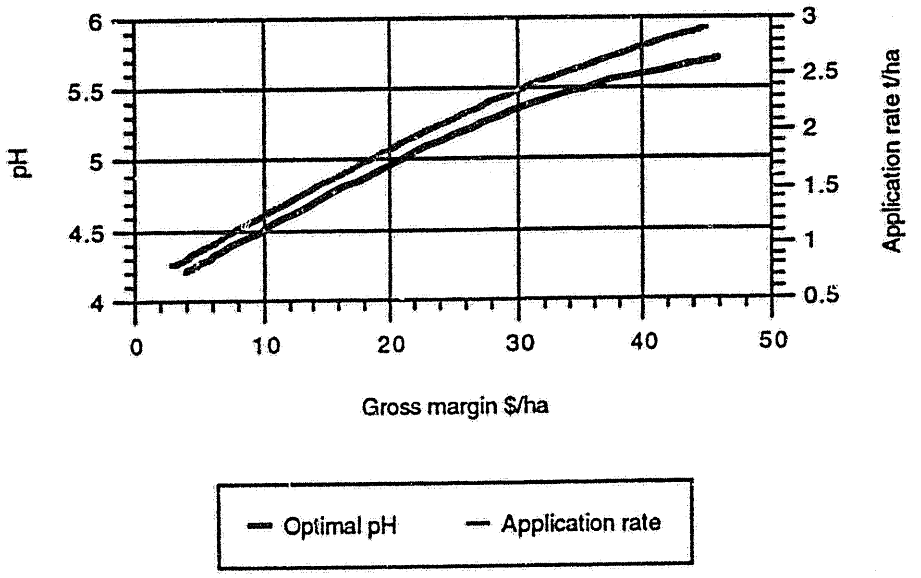


basis of their models, La France and others have argued that subsidies designed to reduce land degradation through output control would be counterproductive. Others argue that the soil is really a capital stock and that its value increases in response to increases in output prices, and therefore that farmers would act to reduce land degradation in response to an increase in output prices (Clarke 1990; Kennedy 1990).

While there may be merit in each of these arguments in particular economic circumstances, the model described by Fisher (1981), would seem to have more direct significance to analysis of situations where remedial action is possible. Under this model, an increase in output price would result in a decrease in land degradation if an increase in output price increased the value of taking remedial action.

The model developed in this paper is based on economic principles espoused by Fisher (1981) but also uses the empirically derived technical relationships from agronomic studies. The model, therefore, has the advantage that it combines empirical and theoretical relationships. On the basis of the model, under all reasonable parameter values, increasing output prices were found to provide an incentive to increase soil fertility by applying lime to increase pH levels. Figure 8 shows the relationship between output price, optimal pH and

Figure 8: Effect of changing wool gross margin on liming rates and optimal pH



lime application rates. It should be noted that it would be profitable to apply lime even if gross margins fall by a substantial amount. This result is particularly relevant as the base gross margins used in this model were derived using the auction prices of $4.90/kg greasy for wool: somewhat below the prices that prevailed before the fall in 1990 but above those prevailing in February 1992. However, if gross margins were to become negative for a sustained length of time, then it would become optimal not to use the land for agriculture. Even with very low gross margins, the response predicted by the model would be to conserve the soil as a productive resource, albeit at a lower pH level.

Conclusions

The programming model simulates the liming rate decisions made by farmers according to profit maximising objectives. In the model, it is assumed that farmers have perfect knowledge about acidity and the effectiveness of liming. There is no provision made for irreversible acidity and the liming technology used is assumed always to be effective in preventing or reversing acidity.

The optimal pH level of soil depends on output and input prices and on real discount rates. If the initial soil pH were above the optimum, then it would be profitable for farmers to allow the acidity of the soil gradually to increase thereby lowering the pH. However, only under extreme circumstances would it be economically rational for a farmer to allow acidity to rise to a stage where the land became totally unproductive. Further, most of the adverse economic effects of increasing soil acidity appear to be site specific. Hence, maintaining soil pH is largely a private issue and private land management is unlikely to preclude major options for the future use of the soil.

Given the apparent economic incentives for farmers to maintain soil pH, instances where soil acidity has been allowed to rise for a considerable period may be caused by lack of knowledge both of the acidification process and of the benefits of liming or other remedial practices. A role for government may be justified to promote greater economic efficiency through funding research to improve understanding of the causes, effects and extent of acid soils and possible remedial measures if such information deficiencies exist.

Several factors need to be taken into account when considering acid soil problems. First, research and extension expenditure should not exceed the efficiency cost of acid soils and, in fact, expenditures should only be made where expected benefits are likely to be greater than costs. Second, the reallocation of funds from other uses by increased taxation or cutting expenditure in other areas should be included as an opportunity cost. Third, as research may not succeed in providing useful results, the chance of success should be assessed and incorporated into estimates of likely benefits when deciding upon the ultimate level of funding. Finally, a further factor which needs to be considered is the possibility of changing other management practices or output. This possibility is not included in the above analysis, but should be taken into account in deciding research priorities.

Technical appendix

The dynamic optimisation model

The model is a discrete time, non-stochastic, non-linear, dynamic model that is solved for the liming rate that maximises the net present value of the stream of annual values of profit per hectare.

The objective function is

$$\text{Maximise } NPV = \sum e^{-rt} \pi_t$$

The equations describing the variables of the model are summarised as follows:

$$pH_t = f(TEC_t, pH_{t-1}, L_t, ST)$$

$$Y_t = g(Ymax, pH_t)$$

$$\pi_t = P_0.Y_t - Pl.L_t - VC_t$$

where

NPV = net present value of profit stream
r = discount rate
π_t = profit in year t
pH_t = pH status of soil in year t
TEC_t = total exchangeable cations in soil in year t
L_t = lime rate in year t
Y_t = yield in year t
$Ymax$ = maximum yield for pasture as determined by agronomic factors apart from acidity
VC_t = variable costs of pasture in year t
Pl = price of lime in year t
ST = soil type
P_0 = output price

The model is optimised over forty years. The terminal condition problem is tackled by assuming that profit in year 40 continues forever. Discounting over the long time frame of the model ensures that the terminal condition is insignificant for decision making in the first thirty years. The functional forms of the pH and yield equations are taken from Cregan, Hirth and Conyers (1988). Values of the parameters are derived from Cregan et al. (1988), Lime-It (1990), and gross margin studies of the New South Wales Department of Agriculture and Fisheries (1991).

The base values for the simulations are as follows:

Initial pH	4.0
Total exchangeable cations of soil (TEC)	4.4
Discount rate	5 per cent
Lime price	$43/t
Application costs	$8/ha
Gross margin for wool production	$23/ha

Note that the above gross margin for wool production is derived using a gross greasy wool auction price of $4.90/kg for 22 micron wool and a stocking rate of 2.2 merino wethers per hectare. The model is solved using a projected Lagrangian method contained in the nonlinear solving package of GAMS/MINOS (Brooke, Kendrick and Meeraus 1988).

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