Economic and Biological Perspectives on Off-site Effects Associated with Soil Acidification

Mullen, J.D[1]., Helyar, K.R[2]. and Pagan, P[1].

1 NSW Agriculture, Head Office, 161 Kite Street, Orange, NSW 2800
2 NSW Agriculture, Wagga Wagga Agriculture Institute, PMB, Wagga Wagga, NSW 2650

Abstract

There is likely to be a divergence in the interests of farmers and their neighbours or the community in the management of land and hence a greater rate of exploitation of soil qualities than that desired by the community. This is particularly true under current institutional arrangements with respect to non-point forms of land degradation, such as soil acidification, where the property rights of the community are weak. Hence it is important to understand the nature and extent of off-site impacts so as to form a basis either for potential collective action or for some form of intervention by government.

One of the objectives of this paper is to draw out the analogies between off-site effects of a spatial nature with those of a dynamic or temporal nature with a view to providing useful insights to biological and economic research into the spatial off-site effects of alternative land management strategies. To make the discussion less abstract the management of soil acidity will be used as an example throughout the paper. To date it would seem that most biological and economic research into this issue has focussed on the temporal dimension.

Contributed paper presented at the 44th Annual Conference of the Australian Agricultural and Resource Economics Society, University of Sydney, January 23-25, 1999. We wish to acknowledge the financial support for this work from the Acid Soil Action - An Initiative of NSW Government. The views expressed in this paper are those of the authors and do not represent those of NSW Agriculture. We have benefited from discussions with staff in NSW Agriculture and Prof. Jack Sinden and Eugene Lim assisted in preparing this paper.

Economic and Biological Perspectives on Off-site Effects Associated with Soil Acidification

Introduction

Farmers decisions about how they use natural resources embodied in land are strongly influenced by what is in their self interest. Their notion of self interest is clearly understood to encompass impacts on current production and land values and may extend to some ‘allowance’ for their personal concern for the environment and future generations. Perhaps less well recognised is the willingness by farmers to pay to reduce the off-site impacts of land use were some means of collective action among neighbours present. Hence as Marshall (1999) pointed out there may be opportunities to devise institutions within ‘neighbourhoods’ that allow farmers to take collective action to manage deep drainage from the root zone (the cause of dryland salinity), for example, to the extent that it is in their self interest both as a group and as individual farmers.

However despite these ‘allowances’ there is likely to be a divergence in the interests of farmers and their neighbours or the community in the management of land and hence a greater rate of exploitation of soil qualities than that desired by the community. This is particularly true under current institutional arrangements with respect to non-point forms of land degradation, such as dryland salinity and soil acidification, where the property rights of the community are weak.

This divergence or failure of the market to deliver outcomes close to community expectations can arise from a number of sources (Godden, 1997) but externalities arising from attenuated property rights are likely to be significant with respect to soil and water quality issues. Externalities can have spatial and temporal dimensions and are often related to each other. Soil acidification for example has a temporal dimension in that soil acidity and agricultural practices in one time period influence future levels of soil acidity. It also has a spatial dimension in that poor plant performance associated with acid soils leads to greater accessions to the watertable and an association with dryland salinity.

While the contribution of externalities to land degradation is widely recognised at a conceptual level, there are a number of issues that are rarely discussed explicitly leading to some ambiguity both about the nature of the problem and policy implications. These issues include:

- the distinction between externalities and off-site effects in both spatial and temporal dimensions;
- the analogies between efficient resource use in temporal and spatial dimensions particularly with respect to the concept of marginal user cost;
- empirical approaches to measuring the divergence between individual and community interests as a guide to the need for government intervention or collective action;

- implications of the joint occurrence of some externalities in land degradation;

The objective of this paper is to review these issues with a view to contributing to a more informed discussion about the interests of individuals and the community in land degradation issues and the potential role of government in addressing these issues. The management of two soil degradation problems that are prevalent in south-eastern Australia and that interact with each other, soil acidity and dryland salinity, will be used as examples throughout the paper.

The distinction between off-site effects and externalities

As van Bueren and Pannell (1999) pointed out, the terms 'on- and off-site effects' are often used ambiguously. In our view this ambiguity extends to the term externalities and to the temporal and spatial dimensions of these terms.

In this paper off-site effects are the effects from resource use decisions on a particular unit of land at a point in time, on other units of land or on the same unit of land at different points in time. Hence off-site effects may have both spatial and temporal components, which is perhaps broader than the usual connotation. Temporal off-site effects are often referred to as carryover or feedback effects.

Externalities are a subset of off-site effects under this terminology, and arise if spatial and temporal off-site effects are not confined to those who cause them. Rather, they have an impact on neighbours and the community whose property rights are attenuated because they cannot choose the extent to which they are exposed to these off-site effects. The significance of the distinction is that in the presence of externalities there emerges a divergence in the interests of individual farmers and the community. This divergence provides the incentive for exploitative resource use.

The classification of off-site effects and externalities also varies according to the perspective of each study. Following are examples of how changing perspective between a paddock, farm or region alters the classification of similar effects.

From a paddock perspective, off-site effects are the effects from resource use decisions on the paddock at a point in time on other units of land (paddocks), or on the paddock itself at different points in time. From a paddock perspective some spatial off-site effects may be contained within the farm. Externalities would arise if spatial and temporal off-site effects are not confined to those who cause them (the current owners/ managers of the farm).

From a farm perspective any spatial off-site effects are likely to also be externalities. This is simply because of the concurrence of physical site (the farm) and individual/group which causes the effects and bears the consequences (the current farm owners/managers). From a farm perspective some of the temporal off-site effects may be borne by the current owners in the future and are therefore not externalities. All other temporal offsite effects from this perspective are externalities.

The interests of farmers are most strongly related to maximising the flow of wealth from the unit of land which they control. Their interest in externalities extends to mitigating the cost of externalities inflicted on them and this may include acting collectively with neighbours. The interest of the community is to maximise a measure of wealth aggregated over all individuals separated either spatially or temporally who are affected by the resource use issue under consideration.

Finally, from the perspective of the region or subcatchment, spatial off-site effects are externalities imposed on communities outside of the region. For example, downstream agricultural and other community members may be affected by upstream activities that affect water quality. Temporal off-site effects will be externalities where the effects are borne by people other than the current members of the region or subcatchment from which the effects originate. Taking a regional perspective implicitly assumes that all people from the region have an equal say in decisions which cause the effects and share equally in the consequences (through the implementation of common property rights or other arrangements).

Modelling in the presence of off-site effects and externalities

Perspective has important implications for modelling off-site effects and externalities. In circumstances where technologies have no spatial or temporal off-site effects the interests of private farmers and the community are the same. Consequently, the choice of modelling unit or perspective is independent of the technology. The impact of the technology is confined to the impact on the unit of land at a point in time. To use Kennedy's (1988) terminology the decision about resource use on a particular plot of land is highly separable from decisions about other plots or for the same plot in other years.

Temporal off site effects

When there are temporal effects the modelling unit is a unit of land through time. The appropriate objective function is to use resources in such a way as to maximise, say, the stream of income from that unit of land over a long enough period to capture the temporal effects. Income in any one period is related to resource use decisions in previous periods and resource use in the current period will have an impact on income in future periods. Simply maximising income in each year without regard to these temporal linkages leads to exploitative resource use and lower aggregate income over the full horizon for which temporal effects persist. This is because the marginal user cost of resource use is being ignored.

From the perspective of the present farmer the planning horizon may only extend to when the farmer intends to sell the farm. The objective may therefore be to use resources efficiently only over this period. Many dynamic programming analyses take this perspective. However if the interests of the community extend to several generations then a much longer planning horizon is appropriate and there may arise a divergence between community and private interests. This divergence in interests will also be influenced by the discount rate used in temporal analyses. The appropriate discount rate often varies between an individual and the community.

Spatial off-site effects

With respect to spatial off-site effects, the choice of modelling unit requires consideration of a much broader range of 'neighbours' and is complicated by the fact that spatial off-site effects are usually separated by time as well. In the case of salt mobilisation by water flows for example, there are potential off-site effects associated with groundwater and surface water systems. From the perspective of a representative farm, off-site effects are potential externalities. The groundwater effects are experienced on land within the catchment or sub catchment that is hydrologically related to the land where the initial resource use decisions are being made, through a shared water table. Hence the land subject to off-site effects may be quite extensive, it may be quite a distance from the original site and it may take many years for the effects to be experienced. In addition, groundwater effects eventually feed through to the surface water systems in the form of increased salt in the stream flow.

One approach is to model representative farms for each of the distinct biophysical parts of the catchment (Greiner, 1988). Each of these farms is linked hydrologically in such a way that resource use in the recharge area affects the watertable in the discharge area which in turn affects production in the discharge area. A representative farm model is required for each area with significantly different biophysical and hydrological features. The difficulty with the representative farm model approach is that some consistent aggregation process is required. To spell this out more fully, while the farm models may represent their environment in being of average size for that environment for example, it is likely that their results will have to be scaled differently to reflect the relative sizes of the biophysical environment they represent. To fully reflect the interests of the community the impact on downstream users through the surface water systems have also to be accounted for.

Estimating the extent of off-site effects and externalities

The existence of off-site effects and externalities and their significance for public policy are widely recognised in the literature. There has long been an understanding of the conditions for efficient resource use through time and there is a growing number of applications of dynamic programming to these resource use questions and these are briefly reviewed below. There appear to us to be two 'gaps' in the literature. First the concepts of efficient resource use and empirical experience gained in analysing resource use through time do not appear to have been widely applied in a spatial dimension.

Second, there is little discussion and few attempts to measure the extent of off-site effects and externalities. This is an important question for resource managers. In the case of public intervention the costs of intervention should be compared with some estimate of the extent of the divergence between public and private interests. In the case of land degradation the fallback position has been to value degradation in terms of production lost, sometimes referred to as the 'production equivalent of degradation' approach, by estimating the change in production at a farm or regional level and applying a value to this change in production. Problems with this approach are discussed in Gretton and Salma (Appendix E, 1996) and in Reeves et al. (1998). A key issue is establishing the benchmark from which production losses are measured. The benchmark is difficult to define but is generally taken to be an estimate of the production that could be achieved from the land in its most likely use were there no degradation. Rarely are the interests of individual landholders and the broader community distinguished.

Kennedy (1988) discussed the issue of separability through time of resource use decisions and noted that when there are temporal carryover effects managing resources as though successive years were separable, that is as though there were no temporal effects, led to less wealth over time than when resources were used a way that recognises these temporal effects.

This suggests that a measure of the significance of these temporal effects can be gained by comparing for a farm measures of wealth when the resources are used as though each year was separable with the situation when resources are used in a way that recognises temporal off-site effects. A similar approach would seem applicable to measuring the significance of spatial externalities. Here the test is to compare for a group of farms that are spatially linked, their income when each firm pursues its own interests with a situation in which the off-site effects are recognised and the farms are managed to maximise the wealth of the group. This was the approach used by Quiggin (1991) which is reviewed in more detail below.

Implementing appropriate policy responses

In addition to the problem of measuring the extent of off-site effects and externalities in a research or policy analysis setting, there is a need to be able to efficiently address instances of unacceptable off-site effects. Government responses in most cases are restricted to the area of off-site effects which are also externalities. That is, Government responds on behalf of (parts of) the community where the welfare of people are affected by the actions of others. However, regardless of whether the off-site effects are part of the externality sub-set, it is necessary to define indicators or proxy variables of the off-site effect of interest so that it can be monitored, if attempts to directly influence the off-site effect is to be possible.

The nature of externalities means that they are best measured at the site of the affected party rather than at the site of the one who causes the externality, as the affected party is unable to control the alteration to their welfare. This situation creates a challenge, as it is also necessary to relate the cost of the externality to some action by those causing the externality. This requires knowledge of the economic cost borne by recipients of the externality, a clear understanding of the physical processes that transfer the externality from the originator to the recipient, and a clear understanding of the technical processes through which actions by the originator cause the externality. An additional difficulty in developing indicator is that there may be a significant stochastic element to important hydrological and biological processes.

The possession of the level of technical and economic knowledge outlined above would allow the development of efficient, enforceable mechanisms which address externalities of concern by directly mitigating adverse effects in accordance with the severity of their impact. Obviously however, this level of technical and economic knowledge is rarely known and second best solutions are implemented as an alternative. These include measures such as the regulation or taxation of those causing the problem on the basis of some proxy measure (such as soil pH or an estimate of groundwater accessions in relation to soil acidity issues) where the tax is set to meet community expectations 'on average'. The choice of measure will depend on how closely it relates to the economic consequences of the externality, and how easily it can be monitored and associated with the activities of those causing the externality.

Consequently, it should be recognised that even with more appropriate recognition of off-site effects in biological and economic research of alternative land management strategies, as is advocated in this paper, there remain significant problems in the translation of this knowledge into appropriate, policy responses that can be implemented efficiently.

The nature and extent of soil acidity and dryland salinity

Soil Acidification

The current acidity status of soils in Australia is the result of a combination of a natural process and agricultural impact. Acid and acidifying soils occur extensively in Australia specially in high rainfall crop or crop/pastures areas. According to the LWRRDC report (1998) there may be 24m ha of agricultural land in Australia that is acidic with a pH of less than 4.8 and the value of production losses may be in the order of $134m. According to the LWRRDC report, the area of acidic agricultural land in NSW and the value of lost production was estimated to be 9.5m ha and more than $100m[1]. The 1986-87 land degradation study in NSW reported that about one third of statistical local areas (SLAs) concentrated in the southeast of the State but extending to the Riverina suffered from severe induced soil acidity and that there were a large number of SLA's where soil acidity was likely to become severe (Gretton and Salma, 1996, p. C10). A survey conducted by Helyar et al (1990) showed that in NSW about 13.5 million hectares of lands have a soil pH less than 5.0 which includes 8.5 million hectares of agricultural land. They also found that

[1] Note that these numbers have not been revised since the 1995 report and it is not clear what year the dollar values relate to.

over 40% of the agricultural land that received more than 500 mm average rainfalls was affected by low pH. There seems to be general agreement that soil acidity is both one of the most important soil health issues and that it is becoming more severe particularly in sandy soils, high rainfall areas and farming systems based on ammonium fertilisers (LWRRDC, 1998, p.8).

Soil acidification is an insidious process that develops under most modern agricultural systems particularly where chemical fertilisers are used and nitrogen fixing species of pastures and crops are grown. In general, the greater the productivity, the greater the potential soil acidification rate. Use of modern production technologies have contributed much in accelerating the rate of soil acidification process over the rate from natural processes.

With the decrease in soil pH, i.e with the increase in soil acidity, imbalances in macro and micro nutrient elements occur which seriously affects plant growth. It can cause aluminium (Al) and manganese (Mn) toxicities while inducing deficiencies of calcium (Ca), magnesium (Mg) and molybdenum (Mo). Phosphate availability in acid soils is low and added phosphate is rapidly rendered unavailable. Imbalances in soil nutrients can cause restricted root growth, adversely affect legume nodulation and can reduce the survival of rhizobia over summer. Limited root growth restricts production of some crops and reduces animal production from perennial pastures (eg lucernes). Acidification of the topsoil eventually leads to acidification in the subsoil. The development of toxicities in the subsoil causes the loss of deeprooted perennial plant species.

While it is technically possible to ameliorate acidity in the topsoil by incorporating lime, ameliorating acidity in the subsoil is a much more difficult problem although Cregan and Scott (1998) refer to a claim by Sumner (1995) that the technology now exists to ameliorate acidity in the subsoil. The management alternatives available to farmers include the application of lime, the selection of more acid tolerant crop and pasture species, and a reduction in stocking and fertiliser rates to reduce the rate of acidification.

The temporal off-site effects of soil acidity are well known. Soil pH in the current period influences the choice of crop and pasture enterprises and the level of production from these enterprises which in turn influence soil pH in the next period. As explained more fully below, farmers have to manage the acidity status of their land to maximise income over time. Soil acidity in this temporal dimension becomes an externality when it imposes unanticipated costs on future generations

Acidification can cause direct off-site effects in a spatial dimension such as the drainage of acid leachate causing fish kills in lakes or streams but indirect off-site effects are likely to be far more significant. The lower productivity and persistence of deep rooted perennial plant species on acid soils means that there is greater opportunity for invasion of weed species and erosion and greater accessions to the watertable which may result in salinity problems elsewhere in the catchment. These arguments are explained in more detail in Cregan and Scott (1998) who agreed with other research concluding that ‘The water cycle is a unifying concept which links many of the significant land degradation/agricultural productivity problems…'.

Dryland Salinity

Agricultural practices have contributed to increased accessions to the watertable. An important cause of accessions to the watertable in recharge areas are changes in vegetation such as the replacement of trees and perennial grasses by annual pastures that use less water where it falls. Walker et al. (1999) have suggested that leakage under farming systems is greatest in high rainfall regions (> 600mm). These increased accessions have two broad classes of consequences. First, land that is hydrologically related to the recharge area may suffer production losses and a narrowing of choice salt tolerant species as the watertable brings salts into the root zone of plants. Dryland salinity is at best a slowly reversible problem requiring greater use to be made of water in the recharge area and by deep rooted salt tolerant plants in the discharge area. Inefficient irrigation practices also lead to rising watertables.

The second class comprises all land or surface water systems affected by the increased salt in the stream flow. Increased salinity in surface water reduces the quality of drinking water and damages infrastructure such as water delivery systems, roads and buildings. It increases the frequency of irrigations that use a volume of water large enough to leach the soil profile of salt delivered during irrigation and hence leads to accessions to the watertable. Additionally it threatens the biodiversity of water systems such as the Macquarie Marshes by favouring salt tolerant plant and animal species. One indicator of the significance of this problem in a subcatchment is to relate the salinity of rainwater to the salinity of water in the surface system at the point it leaves the catchment. A confounding issue is the contribution of groundwater systems to surface water systems.

By 1987 it was estimated that 96,000 hectares of the irrigated land in the Murray-Darling Basin (Murray-Darling Basin Ministerial Council, 1999)were salt-affected and 560,000 hectares had water tables within 2 metres of the surface. By 1998 about 5 per cent of the catchment had shallow water tables, with over 15 million hectares of rising ground water. By 2010 all the irrigation within the southern Basin will have water tables within 2 metres of the surface. The distribution of the high water table areas between the irrigated land on the plains and the foothill and hilly areas has not been summarised for the whole basin. For the Avoca Loddon and Campaspe River catchments in central Victoria however, small increases in the waterlogged area is expected in the next 50 years in the foothill and hilly areas (elevation > 140 M) while large increases are expected on the plains (elevation <140 m). If similar trends occur in NSW where data is limited, only small increases in the area of land directly affected by dryland salinity should occur in foothill and hilly topographic zones. Thus the area of land affected by dryland salinity (salt patches) is likely to remain restricted in rolling to hilly areas over the next 50 years, probably considerably less than 1 million hectares. However these regions are still predicted to deliver increases in salt loads to the river systems of the order of 50 to 100% in different rivers. These increases are significantly affected by increased flow rates from the dryland salinity springs as the water tables rise in the undulating and hilly areas.

Currently water salinity ranges from 40-1440 EC within the Basin. Already, salinity at lower Murray key sites exceeds 800 EC. By 2050, the estimated flow-weighted salinity will exceed the WHO desirable EC limit for drinking water.

Australia wide, according to the LWRRDC (1998):

> 'Dryland salinity currently affects almost 2.5 million hectares in Australia and a further 8 million hectares could be affected over the next 30 years if current land use practices are maintained….. The latest estimate of the cost of dryland salinity is $270m per annum, comprising $170m in lost agricultural production, $100m in damage to rural and township infrastructure and $40m in reduced environmental asset values. (pps.14-15)'.

The joint occurrence of off-site effects

The fact that soil acidification may lead to greater accessions to the watertable and dryland salinity was noted above, as was the suggestion of Cregan and Scott (1998) that the water cycle had important implications for many land degradation issues. The interdependence of some issues is also noted in Passioura and Ridley (1998). Gretton and Salma (1996, p.C12) noted correlation between the Statistical Local Areas in NSW that experience the most severe soil acidity with those that experience the most severe dryland salinity. Despite this much research, literature and policy responses, at least implicitly, treat land degradation issues as though they were independent. Stoneham (pers. Comm.) has suggested that government could manage land degradation externalities more efficiently were their joint occurrence explicitly recognised.

Resource allocation when there are temporal off-site effects

Optimal resource use

There has been much interest in modelling technologies that have temporal off-site effects (Kennedy, 1988). The process of soil acidification through time is a good example but other examples include the more general problem of nutrient carryover (Godden and Helyar, 1980) and the growth of seedbanks in a weeds context (Jones and Medd, 1997). These resource management issues are dynamic in the sense that they deal with a resource stock, such as soil acidity, which influences the level of current production but which in turn is effected, at least in the next period, by current management practises including decisions about liming and pasture and crop choice. There are feedback effects in both directions between the state variable, soil acidity, and control variables such as stocking and liming rates. Hence profit in any year depends not just on decisions made in that year but also on resource use decisions made in previous years.

McInerney (1976) demonstrated that optimal resource use occurred at the point where marginal benefit equals marginal user cost where the latter includes a measure of the benefits lost from using a resource now rather than in some later period -the opportunity cost of resource use in other words. Equivalently the optimal solution to problems of this nature requires the maximisation of profit (and the terminal value of the asset) over a long investment period for the particular unit of land under consideration. In Kennedy's terms resource management decisions of a dynamic nature are not separable from year to year.

Helyar and Godden (1977) and Godden and Helyar (1980) suggested that soil fertility be viewed as a capital resource, the reserve of a given nutrient that is biologically cycling in the ecosystem. This resource can be increased by adding more fertiliser than is being lost from the pool of nutrient involved in the biological cycle (eg. in products, waste products, by volatilisation, leaching or erosion or by fixation in forms that are not cycled biologically). Alternatively the resource can be maintained by adding just enough nutrient to replace losses from the biologically cycling pool or can be depleted by adding less nutrient than is lost or fixed.

In the case of soil acidification the capital reserve is the acid neutralising capacity (ANC) of the soil. When acid is added to a soil, soil minerals are dissolved or H^+ is absorbed on pH-dependent cation exchange sites reducing the soil cation exchange capacity (CEC). These reactions reduce the ANC of the soil and addition of alkaline materials (eg. lime) is required to restore the original ANC.

Off-site effects arise if soil fertility or soil acidity is not being maintained at the that will yield a maximum flow of profit over time. While much of the empirical literature is focussed on how such assets should be managed through time from the landholder's viewpoint, there is little explicit discussion in the literature of how to measure the costs of bad management that results in a rundown of resources and a loss in profit over time.

However in the spirit of Kennedy's (1988) formulation of the objective function that maximises wealth over time, a measure of the significance of these off-site effects to individual landholders could be derived by assessing the difference in wealth when feedback effects are accounted for and when they are not accounted for.

These intertemporal effects are not normally regarded as being externalities because ownership of the unit of land does not change. However when these intertemporal effects last for generations then the issue of intertemporal externalities does arise because there is concern that present generations are likely to exploit resources at the expense of future generations who are unable to express their demands for inputs. Temporal externalities occur when the nutrient capital is reduced in an exploitation phase (ie. a period when nutrient additions are less than losses plus fixation) but the land value does not decline as much as the capital value of the lost nutrient reserve. It has been argued that land values do not always reflect the degraded state of important dimensions of land quality and hence this failure of land markets encourages degradation and imposes an externality on future generations.

The empirical evidence to support this hypothesis is limited. A study by King and Sinden (1988) of land values in the Manilla Shire of NSW where soil erosion was a problem found that the land market appeared to be working satisfactorily but the hypothesis remains to be tested for less visible soil degradation problems such as structural decline and soil acidity. If this is a problem then one remedy is the provision to buyers of objective information about land quality. There seem to be few barriers to the emergence of such a method of selling.

Again the question arises as to how to measure the significance of these off-site effects, now externalities. In a similar fashion to the measure of off-site effects for individual landholders, a measure of the divergence between individual and community interests could be derived by comparing the net wealth of from a farm managed to maximise wealth over several generations with the net wealth of a farm managed to maximise the wealth of each generation with no concern for other generations. An important source of wealth to each generation is the value of the land which appears as a terminal in calculations of wealth over time. If the land market is efficient the terminal value should reflect the net present value of the future stream of income from the farm and hence its quality with respect to nutrient status, acidity etc. Hence the two measures of wealth will diverge if the market value of land of interest to individuals is greater than the stream of income that flows from it to future generations.

Management strategies and their likely impact on off-site effects

The conventional wisdom based on the analyses of trial results (Islam, 1999; Trapnell, 1998; AACM, 1995) and observed farmer practice is that in cropping zones it is profitable for farmers to control pH through the use of lime although it is not clear whether there remains any economically significant divergence in the optimal soil pH from the viewpoints of farmers and the community.

However for the higher rainfall nonarable lands along the ranges where livestock are the main enterprises, it has not been obviously profitable to control soil pH through lime use given the product prices that have prevailed over the last 20 years. From the farmers' viewpoint the appropriate management strategy may be a low stocking rate, low fertiliser native pasture regime that slows the rate of acidification. A feature of these farms is the limited number of diversification options that have been adopted. Enterprises have traditionally been limited to meat and wool production by grazing sheep or cattle. The lack of development of a cropping industry has meant that the farmers did not have the option to grow crops when prices favoured crop over animal production as has been the case in the crop/pasture zone in the wheatbelt. Thus although lime use may have been profitable when animal product prices were high this was not continuously the case. Hence investment in an input with an extended residual effect (an extended period over which returns are received) has been inhibited.

While allowing the acidity of soil to increase in these areas may be an appropriate response from the viewpoints of both landholders and the community, significant externalities may arise if the land market does not adequately reflect the acidity status of the land.

Resource allocation when there are spatial off-site effects

Optimal resource use

The issue of separability also arises when there are spatial off-site effects. They are referred to as externalities when the carryover or off-site effects are experienced by other parties, such as neighbours or the broader community who are not involved in the resource use decisions leading to the off-site effect. Because the resource user does not bear the full cost of how inputs are used on a particular unit of land (or cannot capture all the benefits of input use on a particular unit of land), there is a divergence between the interests of the person who owns the unit of land and those whom his resource use decisions effect.

The treatment of spatial effects or (contemporaneous) externalities would seem to be analogous to the treatment of intertemporal effects[2]. In McInerney's (1976) terms resources are used to the point where marginal

[2] The literature of production economics contains similar problems which may provide useful insights to the issue of land degradation being addressed here. In particular the literature concerning the economics of horizontal and vertical integration of firms and transactions costs may be of interest.

benefits equal marginal user cost where the latter now has a spatial rather than temporal component and represents the losses on other units of agricultural land and other costs to the community. Note that these spatial effects may well be separated in time as well. From society's viewpoint the objective should be to maximise the income not only from the unit of land where the resource decision is being taken but also from all land/users suffering from off-site benefits or costs.

For some externalities there is a relatively symmetric effect on all neighbours or users of the resource. Common examples here include the grazing of the 'commons', and the use of a fish stock or watertable. In these cases the resource user reduces that stock of the resource that is available in the future both to himself and to his neighbours and the impact on the stock is dependent only on the size of the stock at that time and not on the identity of the user. In this case it is in the self interest of all if they can act collectively to control the exploitation of the resource.

At the other extreme is the case of a clear demarcation between those who cause the externality and those who bear the cost. The obvious example here is dryland salinity. The effect on a watertable of removing trees clearly depends on the 'identity' or location of where this occurs. Removing trees in the recharge area may benefit farmers there but cause losses to those in discharge areas. In this case it is not in the self-interest of those in the areas where recharge of the water table occurs to act collectively with those in discharge areas to protect the resource stock, the watertable. Depending on how property rights are defined, those in recharge areas will have to be either taxed or compensated to control their land management (e.g. tree felling) activities.

Many land degradation issues fall between these two extremes of perfectly symmetric and perfectly asymmetric impacts including acidity and erosion. In these cases the production possibilities through time of a farmer are influenced both by the way he uses a natural resource stock, land, and by decisions made by neighbours upstream of him. In turn he has an impact on the production possibilities of downstream neighbours. Hence it may be in the self-interest of farmers to ameliorate to some degree the land degradation on their own unit of land caused by their own actions. It may also be in their self-interest to ameliorate the degradation on their block caused by the actions of upstream neighbours and collective action may be an efficient way of doing this.

From the perspective of the farm, off-site effects are in general potential externalities but as for soil acidity, some spatial land degradation issues occur within farm boundaries and hence present resource use decisions to the farmers where the degradation is sourced. Gretton and Salma (1996) pointed out that even if recharge and discharge areas are on the same property, dryland salinity might arise because the landholder may judge that the higher production from removing trees in the recharge area may more than offset the production lost to dryland salinity in the discharge area.

Often spatial degradation issues are examined from a regional perspective with a view to identifying optimal resource use within a region or catchment. Externalities from this perspective are costs on downstream users. Clearly the interests of individual landholders may diverge from this regional view.

As for the case of temporal off-site effects, a measure of the importance of spatial off-site effects is provided by the difference in wealth were all units of land linked spatially by off-site effects managed as one unit as compared to the 'real world' situation where many spatially linked units of land are managed independently. This principle can be applied both at a farm level where there are off-site effects within the farm boundaries and where there are externalities from a farm or regional perspective.

This approach was used by Quiggin (1991) in his study of salinity in the Murray[3]. Quiggin modelled the different stages of the river with six representative farm models and a seventh stage for urban water use in Adelaide. He first estimated the total profit to the seven regions in the river under an open access regime by solving a series of six LP models where a constraint on the downstream farms was the quality of the water available after the unconstrained management decisions of the farms upstream. Then he simulated a common property regime by formulating the problem as 'a dynamic programming problem in which the stages of the river take the place of successive time periods in a standard dynamic programming problem (p.57), and the objective is to maximise the profit from the farms operated as a group. He found that profit under the common property regime was higher than under the open access regime indicating the extent of the externality problem[4].

It is important to note that under Quiggin's (1991) approach that farms have a capacity to adjust enterprise mix in response to degradation and that some level of degradation may be optimal even from the community's viewpoint. Hence this approach provides more conservative estimates of the cost of externalities which often use zero degradation as the benchmark and are based on crude estimates of foregone production. Critiques of these latter approaches can be found in McInerney (1996) and Gretton and Salma (1996).

Management strategies and their likely impact on off-site effects

The key management strategy being advocated to overcome groundwater off-site effects is the preservation and replacement of trees in the recharge areas with a view to lowering accessions to the watertable (Walker et al., 1999).

---

[3] Jack Sinden referred us to a paper by Barton (1992) given at the 1992 AAES Conference in Canberra that used a similar approach but we have not yet had access to this paper.

[4] It is not clear to us that Quiggin's results hold generally as would appear to be the case for the temporal case where feedback effects are complete. For soil acidity for example, the production function for the unit of land in any period is a function of soil pH which is turn is a function of agricultural practices. In the case of dryland salinity however it appears the feedback effects are not complete. In discharge areas the production is a function of accessions in recharge areas but the reverse may not apply.

They argued that the high rainfall areas bordering the MDB were a particular problem because it was in this region that it was unlikely that agricultural pasture and/or cropping systems could be devised that would provide a reasonable match between water availability and water use and hence minimise groundwater accessions. In these high rainfall areas they argued that the only solution was extensive replanting with trees. However a simple recommendation for the amount of tree cover needed to control dryland salinity that does not account for soil type effects and the amount of salt in the pathway of the deep drainage may lead to control measures that are not economically optimal. The example below illustrates the complexity of the issue of designing optimal control measures and the need for reliable biophysical data to design optimal management methods.

A major source of salt in the Murray-Darling Basin is drainage from the soils in the 500 to 750 mm annual rainfall zone on the inland slopes of the Great Dividing Range between Bendigo in central Victoria to Warwick in south-east Queensland. Solodic soils with sodic, neutral to alkaline subsoils underlying acid surface soils, are widespread on the lower slopes and valley floors in this region. The subsoils typically have very low hydraulic conductivity and the lower A horizon has a sandy loam texture and is often bleached to a pale grey colour due to periodic development of a perched watertable on top of the B horizon. Soils with higher hydraulic conductivity often occur on the upper slopes and hill-crests that are more prone to erosion. Many of these soils are skeletal (stony) with limited development of the soil profile and occupy the area often referred to as the recharge zone. Relatively more recharge is likely in this zone because the soils are shallow and have higher hydraulic conductivity than the duplex soils (soils with a marked decrease in texture between the A and B horizons) lower down the slope.

There is limited knowledge of the detailed patterns of water flow through these soils. It is thought that removal of trees from the solodic soils has led to increased deep drainage through the salt laden subsoils, increasing both the amounts of water and salt reaching the watertable. Increased drainage through the recharge zone contributes more water to the water table but may not be an important source of salt. This has implications for the management of dryland salinity because an increase in the flow of water with a low salt content into streams is not a serious problem. The development of areas affected by dryland salinity depends on a saline watertable breaking out at the surface. The salt is presumably sourced from drainage through saline subsoils or from intersection of saline areas below saline subsoils by a rising freshwater watertable. Detailed knowledge of the water flow patterns is limited however, so the best land management responses are not clear. It may be possible, for example, to control dryland salinity by stopping deep drainage through soils that have sodic or saline subsoils while still allowing high levels of drainage to occur in the recharge zones. Success of this control depends on there being no salt store in the recharge zone soils and on the rising water table not intersecting salt stored under the solodic soils further down the slope.

Some measurements however have found high salt content of water and soil to depths of 12 to 25 metres near discharge sites (from Geoff Beale DLWC pers. com.). So it would be difficult for water of a low salt content avoiding contamination on the way to the surface. However the rate of conversion of the spring to low salinity water would be more rapid than if the whole of the saline soil zone was being flushed.

A further aspect of the bio-physics of the control of dryland salinity is the fact that trees, with a high capacity to dry soils to depth, can create a large soil water store prior to the season when deep drainage is most likely to occur (ie. the season when rainfall exceeds evapotranspiration). At a given rainfall, trees may be needed to control deep drainage where the hydraulic conductivity of the soil is high. Where the hydraulic conductivity of the subsoil is low however, such as for many duplex soils, more of the rainfall is partitioned into surface and subsurface flow, thus bypassing the salt laden subsoil. In such a situation the shallower rooting perennial grasses and forage legumes (eg. phalaris and lucerne) may be adequate to control deep drainage at similar rainfall.

In similar vein, Pannell, McFarlane and Ferdowsian (1999) queried the significance of externalities, at least in Western Australia, as a cause of dryland salinity on both hydrological and economic grounds. They argued that undue attention to externalities has raised the danger that public policy in this area is misdirected.

Care is needed therefore to understand land degradation issues and identify the nature of any market failures particularly with respect to externalities so that any public intervention is likely to meet community expectations.

The joint management of acidity and salinity

An important area for future research is to identify the joint occurrence of land degradation issues. It may be that some areas of high rainfall non-arable land along the ranges are a significant source of externalities associated with land degradation. The payoff to the community from land use changes in these areas induced using some of the mechanisms reviewed by Stoneham et al. (2000) may be quite high.

Conclusions

The objective of this paper has been to note and perhaps clarify some of the ambiguities surrounding off-site effects and externalities relating to land degradation issues such as soil acidification and dryland salinity.

The terms off-site effects and externalities are often used loosely and interchangeably in the literature. One common usage is that the terms off-site effects and externalities have a spatial dimension whereas the terms carryover effects and dynamic are associated with resource use through time. In this paper externalities have been defined as a subset of spatial and temporal off-site effects which are not confined to the person making the resource use decisions.

There are clear analogies between conditions for efficient resource use through time and across space. Farm managers need to account for temporal and spatial off-site effects within their farms as components of marginal cost of using natural resources if they are to maximise wealth from their farm over time. From a community viewpoint the objective is to maximise wealth through time from farms and households managed jointly as though they were common property.

An important distinction is that for externalities the interests of individuals and the community are likely to diverge, creating grounds for potential government intervention. This is generally not the case when off-site effects are contained within a farm (temporally as well as spatially). For government to be involved in ameliorating externalities, the potential efficiency gains (net of the costs of intervention) have to be of a similar order of magnitude to other uses of public funds and there has to be a practical means of intervention.

A guide to the significance of potential efficiency gains may be provided by the divergence between community wealth when land is managed in a way that accounts for temporal and spatial externalities as opposed to the wealth of individuals when these linkages are ignored. Quiggin (1991) used the terms open access and common property to define these regimes. The significance of off-site effects within a farm can be gauged using a similar rule.

The nature of off-site effects associated with soil acidity and dryland salinity and recommended management strategies were discussed in the paper with a view to at least qualitatively assessing the significance of externalities. Typically land degradation issues are treated as though their occurrence were independent events. The significance of externalities and hence the nature of the public response has been uncertain as is evidenced by the discussion of dryland salinity above. Allied with these problems are the difficulties of developing practical means of monitoring externalities and assigning property rights. Hence some have argued that returns to traditional research and extension activities focussing on the interests of individual landholders remain high. Where several types of land degradation occur jointly the use of mechanisms such as auction for conservation contracts may be an efficient way of inducing changes in land use.

References

AACM (1995), *Social and Economic Feasibility of Ameliorating Soil Acidity*, Land and Water Resources RDC, Canberra.

Barton, J. (1992) ………………… contributed paper to the 36th Conference of the Australian Agricultural Economics Society, Australian National University.

Cregan, P.D. and Scott, B.J. (1998), 'Soil acidification - An agricultural and environmental problem', pp 98-128 in *Agriculture and the Environmental Imperative*, edited by Pratley, J. and Robertson, A., CSIRO Publishing, Melbourne.

Godden, D. (1997), *Agricultural and Resource Policy: Principles and Practice*, Oxford University Press Australia.

Godden, D. P. and Helyar, K.R. (1980) An alternative method for deriving optimal fertiliser rates. *Review of Marketing and Agricultural Economics,* ***48,*** 83-89*.*

Godyn, D., Cregan, P., Scott, B., Helyar, K. and Hochman, Z. (1987). "The cost of soil acidification in southern New South Wales." *Australian Agricultural Economics Society Conference*, University of Adelaide, 9-12 February, 1987.

Greiner, R. (1998), 'Catchment management for dryland salinity control: model analysis for the Liverpool Plains in NSW', *Agricultural Systems*, 56(2):225-251.

Gretton, P. and Salma, U. (1996), 'Land degradation and the Australian agricultural industry', Staff Information Paper, Industry Commission, Canberra, June 1996.

Helyar, K.R. and Godden, D.P. (1977), 'The biology and modelling of fertiliser response', *Journal of the Australian Institute of Agricultural Science*, 43:22-30.

Helyar, K.R., Cregan, P.D. and Godyn, D.L. (1990). "Soil Acidity in New South Wales - Current pH values and estimates of acidification rates." *Australian journal of Soil Research*; **28**, 523-37.

Hochman, Z., Godyn, D.L. and Scott, B.J. (1989). "The integration of data on lime use by modelling". In A.D. Robson (ed), *Soil Acidity and Plant Growth*. Academic Press, Australia.

Islam, Q., Mullen, J.D., Brennan, J.P., Li, G.D., Helyar, K.R. and Jones, R. (1999), 'Farming Options for Ameliorating Acidifying Soils in South - Eastern Australia: An Economic Assessment', contributed paper presented at the 43rd Annual Conference of the Australian Agricultural and Resource Economics Society, Christchurch, NZ, January 20-22, 1999.

Jones, R. and Medd, R. (1997), 'The economics of weed control strategies: A dynamic programming analysis of wild oats control', contributed paper to the 41st Conference of the Australian Agricultural and Resource Economics Society, January 25-27, Pan-Pacific Hotel, Gold Coast.

Kennedy, J.O.S. (1988), 'Principles of dynamic optimisation in resource management', *Agricultural Economics*, 2(1988): 57-72.

King, D.A. and Sinden, J.A. (1988). "Influence of Soil Conservation on Farm Land Values". *Land Economics*, 64(3): 242-255.

Land and Water Resources Research and Development Corporation (1998), 'Data sheets on natural resource issues', *Occasional Paper 11/98*, LWRRDC, Canberra.

McInerney,J. (1996), 'Old Economics for New Problems - Livestock Disease: Presidential Address', *Journal of Agricultural Economics* 47, 3: 295-314.

McInerney, J. (1976), 'The simple analytics of natural resource economics', *Journal of Agricultural Economics*, 27(1):31-52.

Marshall, G. (1999), 'Economics of incorporating public participation in efforts to redress degradation of agricultural land' contributed paper to the 43rd Conference of the Australian Agricultural and Resource Economics Society, January 20-22, Christchurch, New Zealand.

Murray-Darling Basin Ministerial Council, (1999) *The Salinity Audit of the Murray-Darling Basin. A 100-year perspective, 1999.* Murray-Darling Basin Commission Office, Canberra

Pannell, D.J., McFarlane, D.J. and Ferdowsian, R. (1999), 'Rethinking the externality issue for dryland salinity in Western Australia', SEA Working Paper 99/11, Agricultural and Resource Economics, University of Western Australia.

Passioura, J. B. and Ridley, A.M. (1998) Managing soil water and nitrogen to minimise land degradation. pp. 99-106 *In* 'Agronomy – growing a greener future.' Edited D. L. Michalk and J. E. Pratley, *Proceedings 9th Australian Agronomy Conference*, 20-23 July,1998, Charles Sturt University, Wagga Wagga.

Quiggin, J. (1991),'Salinity mitigation in the Murray River system', *Review of Marketing and Agricultural Economics*, 59(1):53-65.

Reeves, G., Breckwoldt, R. and Chartres, C (1998), 'Does the answer lie in the soil?: A national review of soil health issues', *Occasional Paper 17/97*, LWRRDC, Canberra.

Stoneham, G., Crow, M., Chaudri, V., Strappazzon, L. and Soligo, J. (2000), 'Biodiversity:Policy mechanisms' contributed paper to the 44th Conference of the Australian Agricultural and Resource Economics Society, January 23-25, Sydney.

Sumner, M.E.(1995), "Amelioration of Subsoil Acidity with Minimum Disturbance, in Jayawardane, N.S., Stewart, B.A. (ed) *Advances in Social Science Subsoil Management Techniques*, pp. 147-184. Lewis Publishers, Boca Raton.

Trapnell, L.N. (1998). "An Investigation of the Net Benefits from Liming Acid Soils". Unpublished M.Agr.Sc. Thesis, University of Melbourne, Australia.

Van Bueren, M.S. and Pannell, D.J. (1999),'Literature review: Regional economic studies of dryland salinity', SEA Working Paper 99/05, Agricultural and Resource Economics, University of Western Australia.

Walker, G, Gilfedder, M. and Williams, J. (1999) Effectiveness of current farming systems in the control of dryland salinity. CSIRO Land and Water, Canberra.