SOIL ACIDIFICATION IN RELATION TO SALINISATION AND NATURAL RESOURCE MANAGEMENT

P.V. Lockwood[A], H. Daniel[A] and B.R. Wilson[B]
[A] School of Rural Science and Agriculture, University of New England, Armidale, Australia.
[B] NSW Department of Infrastructure, Planning and Natural Resources, Armidale, Australia.

Abstract
Soil acidification is one of Australia's major land degradation problems. About half of the more intensively used agricultural land in Australia is acidic, and the area is expanding. A literature review examined research into the problem of soil acidity and acidification in Australia, particularly in relation to salinity. The causes of soil acidification and salinisation have much in common, both being strongly related to the effects of agriculture on soil and catchment hydrology. Estimates of the area affected, rate of spread, and costs of lost agricultural production indicate acidity/acidification to be a far more significant land degradation problem than salinity/salinisation, yet this is not reflected in landholder perception or research effort. Although it has been known for over 60 years that Australian agricultural practices can cause soil acidification, recognition of its significance has been slow. Soil acidity has been managed mainly as an agronomic, paddock scale problem, rather than seen as a natural resource management issue. Recommendations are made for greater integration of research into soil degradation problems with common causes, establishment of a long-term soil monitoring program, more integrated landscape management, and closer examination of the role of native vegetation.

Additional Keywords: nitrate, liming, salinity, acidity, monitoring, native vegetation, landscape management.

Introduction
Acidification of Australia's agricultural soils has become increasingly widespread for about 60 years, driven by expansion of legume-based pastures and increasing use of nitrogen fertilisers. During this time, soil acidity and acidification have mainly been perceived as agronomic problems primarily affecting plant growth, and therefore to be managed at the paddock scale. Because of the low value, low input nature of much of Australian agriculture, practical management recommendations have emphasised adaptation using acid tolerant plants or addressing the immediate causes of poor growth, rather than treating or eliminating the fundamental causes of the problem.

Helyar and Porter (1989) outlined the main mechanisms by which Australian agricultural systems can acidify soil outside acid sulfate soil areas. They are: oxidation of fertiliser ammonium ions, nitrate leaching losses from the soil where the N entered the soil-plant system as ammonium fertiliser or fixed dinitrogen, increase in soil organic matter (ie humic acids), and export of alkalinity as organic anions in plant or animal produce.

There has been considerable research into the use of lime to manage soil acidity, and it is an effective way of neutralising the effects of acidification, particularly near the soil surface. However, lime does not address the causes of acidification, so that, for example, nitrate leaching will continue in a limed acidifying soil. In addition there are limitations to the economic effectiveness of lime application, particularly in the more extensive agricultural systems.

Overall, agronomic approaches to soil acidity and acidification have had considerable success in terms of enhancing and maintaining agricultural production. However, it is argued here that if the problem is going to be fully addressed, it needs to be viewed more broadly as a natural resource management issue which has implications and stakeholders beyond the farm gate. In particular, connections are explored which integrate acidity management with salinity. The study was undertaken as a review of research literature, and presented in a report for the NSW Government initiative – Acid Soil Action (Lockwood *et al.* 2003).

Extent and severity
Audits of Australia's natural resources (NLWRA 2001, 2002) have found soil acidity and acidification to be one of Australia's major land degradation problems. About half of the more intensive agricultural land is acidic at the soil surface (pH_{Ca}<5.5), and although soil acidity pre-dates agriculture, the area is expanding. Slattery *et al.* (1999) summarised 17 publications of acidification rates in 35 Australian agricultural and forestry environments. In all but one of these the soil was acidifying, with pasture and/or annual cropping systems resulting in acid addition rates of 0.16 to 11.4 kmol (H^+)/ha.yr. However, across Australia, the rate of spread of soil acidity is not known with any

degree of certainty. One estimate is that, in the absence of remedial action, an additional 2.7 to 6 million hectares of Australian agricultural land could reach the strongly acidic threshold (pH_{Ca} = 4.8) each year, corresponding to net acid inputs of 1 and 5 kmol (H^+)/ha.yr respectively (NLWRA 2001). By comparison, projections of the increase in land area affected or threatened by dryland salinity are about 0.23 Mha/yr to 2050 (NLWRA 2000). Soil acidity causes an estimated $1585 million/yr in forgone agricultural income while, in contrast, the corresponding estimate for dryland salinity was $187 million/yr (NLWRA 2002).

Despite the impact that soil acidity and acidification is having on Australian agriculture, recognition of the problem has been slow. For example, the first detailed survey of land degradation in Australia, the Woods report (Woods, 1984), did not mention soil acidity or acidification. In 1998/99, 10% of Australian farmers believed they had a significant acidic soil problem, compared to 8% who reported significant degradation due to dryland salinity (Kemp and Connell 2001). Their perception that soil acidity is only slightly more prevalent than dryland salinity represents a gross understatement of actuality, which is that acidity affects production in about 6.9 times the area affected by salinity, and results in about 8.5 times more forgone income due to depressed yields (NLWRA 2002). Similar findings were obtained a little earlier in a national review of the feasibility of ameliorating soil acidification (AACM International 1995). The consultants concluded that soil acidification was not generally perceived as a priority issue by producers and service providers, and that this was a major impediment to adoption of amelioration methods.

Permanent damage to the soil resource

Many of the negative effects that soil acidity has on fertility (eg aluminium and manganese toxicity, and nutrient deficiencies) are reversible in the sense that they can be overcome by raising the soil pH. There are others however which cause more permanent damage to the quality of the soil resource. Subsoil acidity affects about a quarter of Australia's more intensively used agricultural land (NLWRA 2001). Agriculturally induced soil acidification can result in decreased pH through a considerable part of the plant rooting depth. Cregan and Scott (1998), considered that it is generally not profitable for farmers to treat the effects of soil acidification below 20 cm depth. It is therefore effectively a permanent effect of soil acidification. There is also the potential, once soil pH falls to about 4, for hydrogen ions to attack the crystal lattices of clay minerals. This is essentially an accelerated weathering reaction and results in irreversible damage to this key component of soil fertility. The effect has been observed at the Rothamsted Experimental Station, UK, at a site which had been subjected to strong acidification for several decades (Blake *et al*. 1999).

Connections between acidity and salinity

Causes

Australian agricultural systems have tended to substantially increase the amount of water draining below the plant root zone and entering groundwater systems, compared to pre-European landscapes. This is because, prior to agricultural development, these landscapes usually included greater numbers of deep rooted perennial plants, particularly trees, which are more efficient at transpiration than most crops and pastures. This change in landscape hydrology is recognised as the main reason for the spread of salinity in Australia. At the same time, acid soils research has established that loss of nitrate in deep drainage water is probably the greatest contributor to accelerated soil acidification under grazed pasture systems. The causes of agriculturally induced salinisation and acidification therefore have much in common.

Offsite effects of solutes

The adverse impact of salt mobilised by increased deep drainage and groundwater recharge have been well researched. However less is known about the offsite effects of the products of acidification processes and, in a review of the environmental effects of soil acidification, Cregan and Scott (1998) concluded that the relationship of soil acidity to increased runoff and erosion is one about which our knowledge base is deficient.

It has also been suggested that soil acidification can accelerate mineral weathering rates in soils, thereby adding to catchment salt yields. For example in a forested catchment in northeast NSW which was not affected by agriculturally induced acidification, Lockwood *et al.* (1995) found that weathering consumed 1.1 kmol (H^+)/ha.yr, and produced 90 kg/ha of bicarbonate salts in the streams draining the landscape. Agriculturally induced acidification rates are often comparable or larger than this figure, and if a substantial proportion of the hydrogen ions produced were ultimately neutralised by weatherable minerals (eg primary silicate minerals or pedogenic lime), then the resulting bicarbonate salt production could be enough to significantly alter the salt output of a catchment. The extent to which this is happening in agricultural catchments and its consequences have not been investigated.

The major anion leached from soil as a result of acidification is nitrate, and there has been little investigation of its fate. Nitrate lost in deep drainage water has the potential to contaminate groundwater and streams and can be hazardous to health in potable water supplies. In addition there is the possibility of increased nitrous oxide emissions to the atmosphere as nitrate is leached into anaerobic environments (eg groundwater). Nitrous oxide is a potent greenhouse gas, with a global warming potential about 300 times that of carbon dioxide, as well as being a contributor to atmospheric ozone depletion. With nitrate leaching considered to be the dominant mechanism for accelerated acidification, at the lower rate of acidification considered by the NLWRA (2001) of 1 kmol (H^+)/ha.yr, only a small proportion of the nitrate leached from Australian agricultural land would need to be reduced to nitrous oxide to make a substantial contribution to Australia's greenhouse emissions. Furthermore, management of soil acidification by application of lime may not reduce nitrate leaching and nitrous oxide emission, and could in fact enhance it if the maintenance of a more favourable soil pH allows greater rhizobial nitrogen fixation and nitrification.

Managing soil acidity and acidification
In the more extensive but less productive grazing lands broadscale liming as a remedy for soil acidification is probably uneconomical (NLWRA 2002). For this reason, alternative management strategies might need to be adopted. For example, the use of perennial vegetation across larger portions of the land area could potentially reduce soil acidification. This could be achieved by perennial plants using available nitrogen more efficiently thereby reducing nitrate leaching. A more efficient perennial plant cover might also reduce deep drainage and this strategy has also been promoted as a response to dryland salinity.

Over much of the Australian landscape, native vegetation also remains in the form of scattered trees and shrubs. Recent work has suggested that this scattered vegetation cover might ameliorate soil acidification by drawing alkalinity from deeper in the soil to raise surface soil pH. Field studies have also demonstrated that native eucalypts increase the surface soil pH *in situ* in a discrete zone beneath the tree canopy (eg Wilson 2002). Near to the tree stem, soil pH is typically highest and declines systematically with distance away from the tree. For example, pH of up to 1.0 unit higher has been recorded under the canopies of scattered eucalypts (*E. melliodora*) compared with grazed paddocks on the Northern Tablelands of NSW. The scattered native vegetation that remains in the landscape might therefore have a role in the management of soil acidification at a landscape scale (e.g. Noble and Randall 1998; Noble and Randall 1999a; Noble and Randall 1999b; Wilson 2002). Again there are connections with salinity management, with maintenance of trees in the landscape being seen as a key strategy to control salinisation.

Conclusions

The great extent and cost of the soil acidity/acidification problem, its potential to do permanent damage to the soil resource and have offsite effects, and its inter-relatedness with other environmental management problems imply that it needs serious attention as one of Australia's major natural resource management issues.

There are strong linkages between salinity/salinisation and acidity/acidification, in both causes and potential strategies for management. Central to this is the role of vegetation in the control of deep drainage in agricultural systems. There is now a massive research effort in Australia directed at understanding how to better manage vegetation-salinity relationships, including a CRC for Plant-based Management of Dryland Salinity. However the issue of soil acidification in relation to remnant native vegetation in agricultural ecosystems is currently not being well addressed. This research imbalance has the potential to lead to landscapes designed for optimum salinity management, but sub-optimal management for acidity and acidification. There is scope to better integrate research between these two forms of land degradation.

Soil survey data accumulated to date allow reasonable estimates to be made of the current extent of soil acidity in Australia, but we still know relatively little about where and how fast soil acidity is increasing as a result of agricultural activities. A national, long term soil monitoring program is needed to assess spatial and temporal changes in soil acidification. Suitable protocols have already been developed (McKenzie *et al.* 2002). In the absence of such a program and associated modelling and mapping activities, it is likely that in 10 or 20 years time we still will not have good spatial information on the severity of soil acidification processes, nor will we be able to evaluate the effectiveness of remediation and management programs.

More research is needed into the potential for soil acidity/acidification to cause permanent damage to the soil resource and to have offsite effects.

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