Chapter 4

Major affects of soil acidification

The optimum soil pH for plant production is one that is slightly acidic, at this pH soil microorganisms are most active and plant nutrients are readily available. At extremes of high (alkaline) and low (acid) pH this delicate balance is disturbed and plant nutrients that were in adequate supply can become either deficient or toxic to plant growth. Some essential nutrients such as phosphorous, calcium, magnesium, and molybdenum become unavailable if the soil pH becomes too acid. Acid conditions will result in a lowering of plant production in farming systems. This will result in reduced profitability and an increased reliance on fertilisers to sustain any form of productive agriculture. Correcting soil pH to a more favourable pH range will increase the availability of essential nutrients.

Nutrient toxicity can occur in acid soils when the pH_{Ca} is 4.8 or lower (Slattery *et al.* 1999). The two most important toxicities in acid soils are those of aluminium (Al) and manganese (Mn) (Slattery *et al*.1999). In strongly acid soils (pH_W < 4.3) aluminium and manganese become more available in the soil solution and are harmful to plant roots. Aluminium toxicity is the most common plant symptom on acidic soils and causes root stunting (Slattery *et al.* 2000). Reduced root growth impedes nutrient and water uptake and results in decreased production. Some plants are more tolerant than others to high levels of Al in the soil solution; however, as the pH declines so too do the farming options for utilising plants that are aluminium tolerant.

There is a danger in the development of more acid tolerant cereal and legume cultivars, since the use of these acid tolerant crops has the potential to further extend the use of the soil resource in the strongly acid pH range. If this happens, then soil degradation could reach a level, which is irreversible. The use of these practices will lead to a poorer soil resource that is expected to maintain current crop production, and one that cannot be returned to its former state. Clearly, there is a need to conserve this valuable resource as much as possible and preventing soils from becoming strongly acid is one strategy.

Important productive plants such as lucerne, phalaris, canola and barley are difficult to establish and grow in acidic soils. Both low pH and toxic aluminium (Yokota and Ojima 1995) irreversibly affect the establishment of lucerne. The growing of deep-rooted perennial pastures (such as lucerne and phalaris) is seen as an answer to slowing the acidification process (Ridley *et al.* 1998). If these plant species cannot be established because soil pH is too low, then nitrate leaching will continue, thus increasing the rate of acidification and increasing the recharge of water into aquifers, leading to further dry land salinity problems.

Recent work by Slattery *et al.* (1998) has shown that soil clay loss from primary clay minerals is a severe consequence of allowing soils to remain at a pH_{Ca} of 4.0 or lower for an extended period (10 yrs). Over the time frame of one farming generation, little apparent harm is done to the soil's mineral framework by permitting acidification of weathered soils. However, it is clear that permitting unabated acidification over longer periods will cause the soil to continue losing clay and to increase its silica content.

The use of liming materials to prevent the soil from becoming too acidic is essential to prevent this irreversible soil degradation. Estimates indicate that only 22% of the total area of soil affected by acidity in Australia is currently limed (AACM 1995). Of the 90 million hectares of land affected by soil acidity, about 5% of this is strongly acidic (ie. pH_{Ca}<4.8) (Slattery 2000). Some of this land already receives lime, however the remainder will require immediate liming in order to remain productive in the long-term and prevent irreversible degradation of the soil.

The extent of acidity is increasing in the surface soil layers of cropping soils in all major grain growing regions of Australia (Coventry 1996, Slattery *et al.* 1997). Although the sub-surface soil layers are often alkaline in many of these regions some can be acid and they are also often hostile, in that they can be sodic or saline or both. It is the surface soil layers that provide the rich fertile soil environment for nutrient supply to plant roots, and they must be protected from irreversible clay loss due to soil acidity. An additional concern if surface soil acidity continues without abatement, is the risk of developing acidity in previously neutral subsoil. Subsurface acidity is difficult to remediate due to the slow movement down the soil profile of neutralising materials such as lime and base rich organic matter (Ridley *et al*. 1992, Myers and De Pauw 1995). Some soils of a granitic nature already have serious subsoil acidity problems which inhibits the growth of plant matter and exacerbates dry land salinity as these soils are generally located in recharge areas. Although the pH of these granite subsoils has been exacerbated by agriculture, recharge control on these soils will require special attention.

Impacts of soil acidification

Soil acidification has a negative impact upon a range of natural resource functions. Some of these have wide community impacts through soil degradation, and include the loss of native biodiversity, that may impact on recreation and tourism. These areas include the following and are discussed in detail below.

- **Soil microbes**
- **Forestry**
- **Soil animals**
- **Acid sulphate soils**
- **Aquatic biota**
- **Infrastructure**
- **Human health**
- **Animal health**
- **Weed control**
- **Soil structure**

Soil microbes

Australian soils are low in nitrogen content and plant growth relies on the ability of many leguminous plants to fix atmospheric nitrogen through a plant symbiosis with the soil microorganisms. The affect of different soil environmental conditions in pastures and broadacre crops on the *Rhizobium* legume symbiosis has been studied extensively and is detailed in a recent review by Slattery *et al.* (2001). Soil acidity limits *Rhizobium* survival and persistence where elevated levels of aluminium have been shown to be directly toxic to the growth of Rhizobia affecting nodule initiation and the nitrogen fixation process (Slattery *et al.* 2001). Many Victorian soils are already at a pH where clover nodulation is reduced which has a significant impact on the productivity of pasture and subsequent crop systems that rely on the biological input of nitrogen.

It is the production of this nitrogen which, if not fully utilised by plant roots can be leached, causing further acidification. At very low soil pH and under conditions of high soluble aluminium it has been shown that Aluminium can have a metagenetic effect on Rhizobia (Wood 1995). These findings suggest that the microbial biodiversity might alter over time with changing soil pH. The effects that this may have on plant growth through root symbiosis, microclimate pH and nutrient bioavailability is largely unknown. The study of the affects of soil acidification on the symbiosis of the native Rhizobia is just beginning.

In highly weathered acidic soil, bacterial growth is inhibited by nutrient toxicities and low nutrient availability. Acidity changes the soil microbial community and decreases root and rhizosphere effects. It decreases decomposition and nutrient transformation for root growth and increases mycorrhizal occurrence and establishment, both essential for nutrient uptake under strongly acidic nutrient poor conditions (Sequira 1997). Acidity decreases the activity of nitrifying bacteria responsible for the breakdown of organic matter into ammonium and nitrate for subsequent plant uptake. Fungi generally have a pH optimum below that of bacteria, however if the soil pH is strongly acid then the biologically driven processes such as stubble breakdown are slowed due to low fungal activity. In addition, the decomposition of plant residues by fungi under waterlogged conditions will lead to a further decrease in soil pH as toxic acetic acid is produced (Lynch 1995).

Forestry

Plantation forestry involves the bulk removal of vast quantities of biomass, which has the potential to acidify the soil over a relatively short time period. For example, in New Zealand, *Pinus radiata* plantations acidified soil due to the combined effect of product removal and pine needles, to a greater extent than an adjacent perennial pasture (Giddens *et al*. 1997). However Noble *et al*. (1999) could not demonstrate this same pH decline between a 40 year old Pinus radiata and an adjacent perennial pasture in the ACT. In another study in central Victoria (Axe Creek), the removal of native eucalypt timber followed by regrowth from stumps acidified the soil to a greater extent than an adjacent unimproved pasture (Prosser *et al*. 1993). Clearly there are other factors that play a role here, of which soil type and rainfall may be major contributors.

Large amounts of cations are contained in forest thinning, timber and the leaves of some species. Therefore it is likely that the removal of some or all of these components from the plantation will result in a lowering of soil pH. Failure to add sufficient lime during plantation establishment or after logging operations resulted in the lowering of soil pH and a raising of the aluminium to toxic levels (Prosser *et al.* 1993).

Different tree species however, have varying abilities to modify the soil pH in which they live. Some deciduous species (eg white beech *Melia azedarach, Populus nigra*) bring significant amounts of basic cations (predominantly calcium) to the surface for subsequent amelioration of surface acidity (Noble *et al*. 1996, Noble and Randall 1999). This is only useful in soils that are highly buffered or are alkaline at depth, as the altered nutrient distribution would result in significant subsoil acidity in some soil types. In contrast to this, the water-soluble fraction of some *Eucalyptus* species' leaf litter has the ability to complex with cations. The downward movement of these soluble compounds will result in a loss of cations from the surface profile hastening the acidification process in the surface soil layers. There is also evidence that some *Acacia* species (*melonoxylon, elata*) are neutral in their impact upon the acidification process and this can be attributed to the cation and soluble organic matter fraction content of the leaf litter. Their leaf litter being low in cation content and having low cation complexing ability (Noble and Randall 1996).

Soil fauna (invertebrates)

Soil acidification changes the delicate balance between groups of living organisms in the soil, due to the preference of soil fauna for specific pH environments. Generally, the soil fauna has a significantly reduced capacity to cope with large changes in pH. In tropical environments where some soils have been acid for a long period of time the soil fauna have evolved a tolerance to low pH. However, most macrofauna including deep burrowing species such as worms and termites tend to decrease in abundance in acidic soil conditions with most activity being confined to the litter layer where the pH is significantly higher and usually alkaline.

It has been shown that earthworms improve soil structure due to the formation of burrows (Tisdall 1985), and contribute to the redistribution of nutrients within the soil profile (Baker *et al*. 1993). In north eastern Victoria it has been shown that a reduced abundance of earthworms is associated with acidic soil conditions (Mele and Carter 1999). These reductions in earthworm numbers will contribute to the decline in structural quality of the topsoil for plant growth. Worms play an important role in the turnover of organic matter and in providing suitable substrates for the meso and micro fauna. Some worm species are able to tolerate acid soil conditions and play an active role in litter decomposition, but these worms are also highly affected by the moisture conditions surrounding them (Lavelle 1995). In contrast to this the deep burrowing and soil eating worm species are unable to tolerate low soil pH conditions (Lavelle 1995). This then limits their ability to improve soil structure in acidic soil.

Acid sulphate soils

The formation of acid sulphate soil and subsequent waterway acidification is confined to densely settled coastal and floodplain areas, mostly in the tropics where development has been expansive and other options for agricultural and urban expansion do not exist (Ritsema *et al.* 2000). Acid sulphate soils arise when sediments containing the mineral pyrite are exposed to air through drainage or excavation. This results in the production of sulphuric acid that subsequently leaches iron, aluminium and manganese into tidal reaches. Fish kills, fish disease, reduced aquaculture and marine plant production, stream ecology changes, infrastructure corrosion and acidification of previously potable aquifers (White *et al.* 1995) arise as a result of these toxic flushes.

Aquatic biota

Water pH is only now being recognised in Australia as a potential problem and streams that have previously been neutral to basic are now acidic. For example, rivers in the Goulburn and Broken River catchments in NE Victoria have experienced a 1.0-1.5 pH_W unit drop over the ten-year period from 1982-1992, with current river and stream pH values in the Goulburn Basin ranging between 6 and 7.5 (Shalcken 1996). At this rate of pH decline the health of our inland river systems may be a concern in the near future.

Both catchments are reasonably undisturbed in the upper reaches and yet this pH drop has occurred in both disturbed and undisturbed portions of the catchment. The reason for this drop has not been fully elucidated, as the most likely cause, episodic acid additions from ground water flow through bedrock, is poorly understood (Shalcken 1996). In Australia, there has been little evidence to date that soil acidity as caused by agricultural production has affected stream water pH. In Europe and North America there are strong links between acid rain, aerial-acidic-particle deposition, soil acidification and the consequent lowering of pH in streams and lake waters. However, recent findings from South Africa have shown that stream acidification has occurred in limited areas of very poorly buffered catchments (quartzite soils) due to agricultural production (Fey 2001). In these studies, plantation forestry has led to decreasing soil pH that in turn has acidified stream waters relative to the water draining under natural grassland in a comparable catchment (Fey 2001).

The Australian and New Zealand Environmental Conservation Council (1992) "Australian Water quality guidelines for fresh and marine waters" state that freshwater pH_W should ideally be within the range 6.5 – 9.0. Natural fresh waters are usually at pH_W 7. Values of water pH_W between 6-9 are not lethal to fish, but values between 5-6 can effect the reproduction of sensitive species (ANZECC 1992).

In Victorian waterways the pH_W levels are already at values around 5 – 6 suggesting that some change in biodiversity may have already occurred. Additional studies are needed to identify the impact of declining soil pH on our waterways and the subsequent changes in the aquatic ecosystems.

Infrastructure

The direct effect of soil acidification on infrastructure such as roads and building foundations is not known in Australia. However, some work in Europe and the United States of America has shown that acidifying the soil has a dramatic effect on the stability of concrete and the bitumen used for road surfaces (de Belie *et al.* 1996).

For example the presence of the organic compounds, lactic and acetic acids together with volatile fatty acids secreted by plant roots in acidic soil conditions (pH_{Ca} values around 4.0-5.0) are capable of causing the aggressive corrosion of concrete surfaces (de Belie *et al.* 1996). In addition to this study, it has been shown that concrete will deteriorate with the subsequent corrosion of the steel reinforcement under acidic soil conditions (Balasubramanian *et al.*1988). It is also acknowledged that microorganisms are responsible for some of the decomposition observed with building foundations. However, only recently it has been demonstrated that a particular dark green fungus is tolerant to acid soil conditions even though its optimum growth range is near neutral pH (Cho *et al*. 1995), thus exacerbating the deterioration of concrete under acid soil conditions.

The impact of acid soils on road surfaces is linked to an association of acidity effects on roadside vegetation. In a study involving the comparison between road stability on acidic and non acidic soils (Auerbach *et al*. 1996), it was shown that the lack of vegetation on the acid soil led to a more rapid soil loss, which caused significant and long-term destruction of road structure. These documented impacts on infrastructure decline differ according to the chemical and biological composition of the soil.

The impact of low soil pH on concrete building structures is a constant source of concern for the building industry and ameliorative measures, such as liming are commonly used during construction to stabilise soil foundations. In severe situations where acid sulphate soils dominate, the effects on building foundations are devastating. A good example of this form of concrete corrosion is the Burnley tunnel in Melbourne.

In addition to the impact of soil acidity on road surfaces and building foundations, the combined effect of water movement and salinity can be harmful and may require significant reconstruction costs to repair damaged structures. For example the ability to vegetate areas of high runoff in high rainfall regions will be very much dependant upon the pH of the soil. As the pH declines so too do the options to retain groundcover on much of the hillslopes. As a consequence water flows are dramatically altered causing significant changes in watertable and thus saline conditions in other parts of the catchment. Unpredictable water flow episodes over road surfaces may cause lifting of bitumen and result in an increased cost to road maintenance.

Human health

There is little specific information available on the direct impacts of soil acidification causing problems to human health. Of significant importance to human health however, is the fate of chemicals applied to soil for the control of weeds and insect pests. It has been shown that some chemicals applied to low pH soils with high organic matter content will remain relatively unchanged compared to when they are applied to high pH soils of even low organic matter content. (Andreux *et al*. 1995) The degradation of chemicals applied to soil is also dependent upon the role of microorganisms, which if affected by low soil pH will be ineffective in the biological degradation of these soil pollutants (Stotsky 1986).

In Australia, the use of phosphatic fertilisers with inherent low heavy metal contents is the main input of heavy metals into the farming landscape (Oliver *et al*. 1996). Most heavy metals are bound and relatively immobile in alkaline soils however, under strongly acidic soil conditions the availability and mobility of some of these elements is increased (Tichy *et al*. 1997). As soils become more acid, crop plants can take up metals such as cadmium, which may reach levels higher than the maximum permissible level for human consumption (Oliver *et al*. 1996). As soils acidify in the Victorian landscape the potential for the uptake of heavy metals may also increase, representing a real concern for human health, and Australia's "clean and green" image for export produce.

Animal health

The impact of soil acidity on plant growth has implications for animal species that use those plants as their only source of nutrition. It has been demonstrated that plants grown in strongly acid soils can become deficient in some essential elements such as calcium, magnesium, sodium, potassium, boron and molybdenum. In addition, toxicities of aluminium and manganese can also occur (Slattery *et al*. 1999). The implication of these changes in plant health for livestock production is largely unknown, but it is likely that poor health and a general lack of resilience to harsh conditions will prevail.

Weed control

Most plant species grow optimally in a soil pH_{Ca} environment that is between 5.0 and 6.5, with pH values below this range causing a significant reduction in plant viability. Weed invasion in low pH soils is common because introduced species are unable to cope with poor fertility and Al toxicity in strongly acid soils.

In general, undesirable acid tolerant species are less economically viable with many weed species such as Sorrel, Capeweed and Paterson's curse thriving in these low soil pH environments. In order to maintain a diverse range of plant species over much of our landscape it will be important to consider soil pH as one of the primary limitations and liming programs will be needed.

Soil structure

In strongly acid soils the potential for reduced vegetation is dramatically increased and thus the potential for soil losses due to water and wind erosion are also increased. Soil microorganisms and organic matter are major components in the formation of good soil structure. Soil microorganisms degrade the organic matter into small fractions that provide the glue that ultimately holds the soil particles together. In low pH soils microbial populations are reduced resulting in a reduced capacity to degrade organic matter. Consequently, low pH soils are more loosely held together and are more likely to be degraded through external influences such as high rainfall events, drought and agricultural disturbance of the soil.

For strongly acid soil environments there is an additional loss in soil structure due to the loss of fine clay fractions (Slattery *et al*. 1998). This type of degradation occurs when soils are allowed to decline to a very low soil pH and remain at this pH for a period of 10 years or more.

Table 6. Summary of the impacts of soil acidification on natural ecosystems (forests, soil biota), waterways, weed control, soils and agriculture.

Component	Likely effect of soil acidification
Microorganisms	Low soil pH leads to reduced growth of beneficial organisms such as Rhizobia, thus reducing plant growth. Low pH results in a change in the microbial biodiversity, implications of this are unknown, but potentially may impact upon decomposition processes (essential for the release of nutrients from organic matter) and in symbiotic relationships between native vegetation and soil organisms decreasing the survival of native vegetation.
Soil fauna (invertebrates)	Earthworms and some insects are unable to tolerate low soil pH, and the resulting reduction in numbers will lead to poorer soil structure and reduced organic matter decomposition. The affects on ants and other soil fauna is completely unknown.
Forestry	Natural and introduced plantations lead to a lowering of surface soil pH although some tree species (Acacia's) have a neutral impact on soil pH. The rate of acidification and impact on surface and subsoil pH will depend upon tree species, harvest systems and harvest rates.
Aquatic health	Stream pH has declined by 1.0 to 1.5 units over the past 10 years. Geological processes seem to dominate this change in river pH. The link to soil acidification is not clear, although plantation forestry has been shown to influence river pH decline. The capacity of native fish species to survive and breed in lowered pH conditions is unknown.
Animal health	Acid soils have an impact upon the nutrient quality of plant species. The impact of nutrient imbalances in plants on animals grazing on acid soils is not known.
Weed control	Reduced tolerance to acidity by most productive plant species allows some weed species to dominate and thus reduce the biodiversity of the landscape.
Soil structure	Decreasing soil pH will lead to reduced vegetation and increased soil loss due to water and wind erosion. Very acid soil conditions will lead to irreversible clay loss.
Agriculture	Unable to grow acid sensitive species such as canola and lucerne. Soil clay loss is increased as soils become strongly acid (pH 4.0 and lower).