SOIL ACIDIFICATION IN PASTURES ON THE NORTHERN TABLELANDS OF NEW SOUTH WALES, AUSTRALIA: OPTIONS FOR MANAGEMENT

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Abstract
Soil acidification resulting from agriculture is recognised as one of Australia's foremost land degradation problems, yet over much of the landscape little is known about the distribution and extent of soil acidification processes. This lack of knowledge is a serious impediment to effective management of the problem.

A paired-site study across a range of soils on the Northern Tablelands of New South Wales (NSW), Australia, investigated the extent of accelerated soil acidification under managed pastures in a temperate climate with summer-dominant rainfall. Forty-one paired sites, each comprising a roadside reserve of native pasture and an adjacent paddock of the same soil type but with exotic pasture, were used in the study. Soil samples collected from the reserve and paddock areas of each site were tested for routine chemical parameters and the results statistically analysed. Data from the analyses showed differences in soil chemistry between paddock pairs that could be attributed to pasture and grazing management. This paper presents preliminary results from the study. Implications of the problem are discussed and appropriate management options, including lime amendments, are considered.

Introduction
Under natural conditions soils may slowly acidify over time, but agriculture and pasture management can accelerate acidification (Lockwood et al., 2003). Agricultural management practices that can affect soil acidification processes include growing legume pasture species, applying nitrogenous fertilizer and removal of produce. These practices influence the nitrogen and carbon cycles, the major components of acidification processes in the soil. Principal processes of soil acidification in sown, fertilized pastures are loss of nitrate in leaching or runoff; nitrification of ammonium fertilizers; production of organic acids from a buildup of soil organic matter; and export of organic anions with product removal (Helyar and Porter, 1989). Soil acidification can cause pasture degradation and loss of productivity (Fenton et al., 1996), aluminium and manganese toxicity, molybdenum, calcium and magnesium deficiencies, and reduced nitrogen fixation. Symptoms of aluminium toxicity include poor root growth, shallow roots and stunted plants.

The study reported here was part of the first full-scale project to assess acidity and acidification in northern NSW. Considerable research into the processes of soil acidification has been undertaken in southern NSW where winter rainfall prevails. Soil acidification in northern NSW is less well understood but it is expected that the processes will vary from the south with differences in climate and pasture management. That soil acidity and acidification on the Northern Tablelands were of concern to most landholders interviewed as part of the study gives further recognition to this significant soil degradation issue.

The main objective of the study was to assess the impact of agricultural management on soil acidity associated with pasture and grazing management on the Northern Tablelands. By identifying those areas most at risk of soil acidification, appropriate management options can be recommended, and plans to help control the rate of acidification in the region can be devised.

Materials and Methods
To determine whether pasture management was accelerating soil acidification, an across-the-fenceline survey was undertaken. A paired-site approach was used as it enabled a direct assessment of any changes to a soil with management. For each site, one side of the fence was a native pasture and this provided a control. Over the fence, the soil was the same type but superphosphate had been applied and exotic pasture sown. Differences in soil chemistry between the two areas could be attributed to management, and each pair of sites provided duplication in the design of the experiment.

The Study Area

Sites for this study were confined to the Northern Tablelands, which extend from Tenterfield (29°S, 151º50'E) and south to Nundle (30º25'S, 151º10'E), and are bounded by an escarpment along the eastern boundary and a steep erosion scarp in the west (Harrington, 1977; Walker, 1977). Altitudes of the tablelands are between 1 000 m and 1 300 m with gentle rolling country and shallow open valleys (Walker, 1977). Summers are usually moist and warm and winters are dry and cool. Soils of the tablelands include Vertosols and Ferrosols/Dermosols derived from basalts; Tenosols/Kandosols/Kurosols and Chromosols from granites; and Yellow Kurosols and Yellow Chromosols from metasediments (Isbell, 1996).

Site Selection

Forty-one paired sites were selected following strict selection criteria. Each site comprised a roadside reserve of native pasture and an adjacent paddock of exotic pasture. Soil type and landscape attributes had to be the same either side of the fence. The paddock had to have been routinely top dressed with superphosphate and regularly grazed with sheep or cattle or both. Permission to sample was needed from landholders, together with a full management history, including fertilizer application rates and pasture improvement details. A site was rejected if the paddock had ever been amended with lime. The reserve was not to be degraded, but it could be occasionally grazed and this was not uncommon during severe drought conditions.

Soil Sampling

At each site area two parallel transects, 17.5 m long and 10 m apart, were set up perpendicular to, and either side of, the fence. One set of three cores was taken from each transect. On each side of the fence the cores were 7.5 m away from the boundary, then at 5 m intervals along the transect. This design avoided sampling in an area where fenceline effects such as vehicle or animal tracks, subterranean telephone cables or other disturbance could influence soil physical or chemical attributes. On the roadside reserve the outer, or first pair of, cores had to be at least 10 m from the road to avoid contamination from roadworks or vehicles. The transects also had to be at least twice the canopy radius away from any tree owing to the influence of tree canopies on soil acidity. Each core in a set had a corresponding core in the adjacent parallel transect, a total of six pairs of cores for a site. The cores were 50 mm in diameter and 30 cm deep except the middle core of each transect that was 50 cm deep. Core pairs were laid on a sheet of corrugated polycarbonate roofing material and sub sampled to 0-5, 5-10, 10-20, 20-30 cm, and where applicable to 30-40 and 40-50cm, depth intervals. Equivalent sub samples from each pair were bulked in the field and each bulked sample placed in a clearly labelled clip-seal plastic bag.

Laboratory Analyses

The bulked soil samples were air dried, hand sieved to pass 2 mm and put through a sample splitter. One set of samples were combined to produce a single sample for each depth interval of each area within a site. Thus, for each side of the fence six bulked sub samples, one each for 0-5, 5-10, 10-20, 20-30, 30-40 and 40-50 cm, were produced. These samples were tested for pH in calcium chloride (1:5 soil/0.01 M $CaCl_2$ suspension) (pH_{Ca}), pH in water (1:5 soil/water suspension) (pH_W), organic carbon, nitrate-nitrogen, ammonium-nitrogen, total nitrogen, phosphorus (Bray P), sulphur (KCL-S) and exchangeable cations including aluminium. The second set of the split samples were tested for pH_{Ca} and pH_W to assess any pH change across the boundary between the paddocks. Any abrupt change would indicate that this was the result of management (Moody and Aitken, 1997).

Statistical Tests

Statistical analyses were run for each variable with pH_{Ca}, pH_W,, organic carbon, nitrate-nitrogen, ammonium and total nitrogen, available phosphorus, sulphur and exchangeable cations reported here. The analysis of variance was non standard as depth increments could not be randomly allocated for serial correlation between depths. To test these data from non-independent soil depths, a repeated measures series was formed and analyses had to assess non-constant spatial correlation. Tests of antedependence (Kenward, 1987) showed first or second order dependence for these variables. Thus, for a particular depth, an observation was influenced by those of the adjacent one or two shallower depths. For example data for a sample from 30-40 cm were correlated with the two previous depths 10-20 and 20-30 cm but were independent of the shallower depths of 0-5 and 5-10 cm. Data from individual depths were analysed by using data from shallower depths as a covariate to assess significant changes between the paddock and reserve. Cubic smoothing splines (Verbyla *et al.* 1999) for smoothed profiles were also employed.

Results and Discussion

Significant (P = 0.05) differences between the reserve and paddock for pH_W (Fig. 1) were evident for the depths 0-5 and 5-10 cm, and, after adjusting for the previous two depths, for 10-20 cm. Paddock soils were generally more acidic than those of the reserve. The spline analysis showed no convergence of the two profiles which implied a parallel response between treatments. This suggested a management and depth effect was present for pH_W. For pH_{Ca} (Fig. 1) a significant difference was only evident in the 5-10 cm layer after adjusting for the shallower depth, 0-5 cm. Convergence of the two profiles was evident from the spline analysis and this suggested a depth effect but no management effect. pH_{Ca} would be expected to display a similar pattern to pH_W down the profile, but be between 0.8 and 0.6 pH units lower than the pH_W of between 5.7 and 6.9 units reported here (Henderson and Bui, 2002). The apparent anomaly in these results could be within experimental error, but will be further examined.

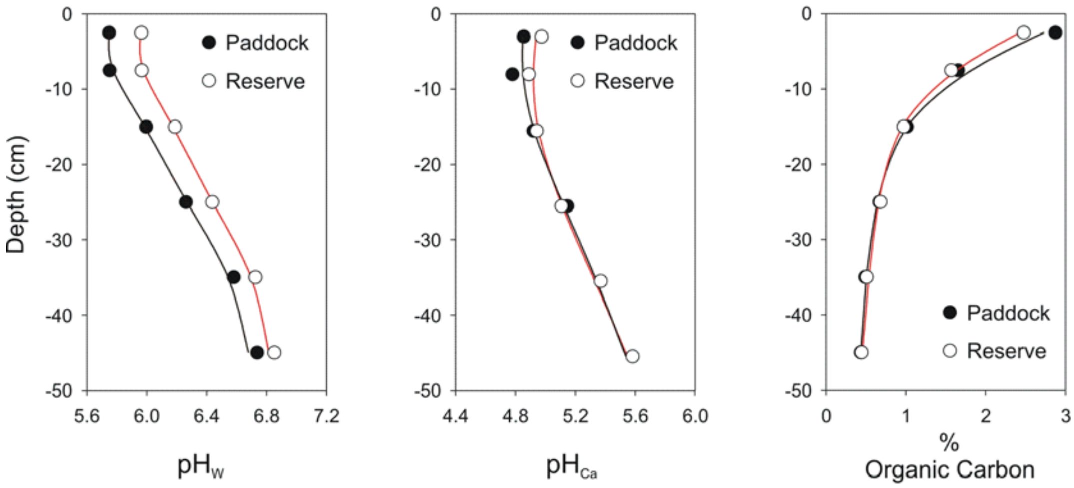

Fig 1. Differences between paddock and reserve for pH_W, pH_{Ca}, and Organic Carbon

Organic carbon (Fig. 1) showed depth effects but no treatment effects. The spline analysis showed significant differences between the reserve and paddock at 0-5 cm. Given the small difference between the paddock and reserve, it is expected that organic carbon is not a major contributor to the acidification process. Nitrate, ammonium and total nitrogen (Fig. 2) showed significant differences (P = 0.05) for 0-5 cm with higher values for the paddocks. The difference between the nitrate values can be attributed to nitrogen fixation from the pasture legumes. This difference was evident to 20 cm and this implies nitrate movement down the profile. Total nitrogen displayed a strong depth effect, but only a very slight interaction for treatment. Further analyses to assess the interaction between these variables and as they relate to soil type will be undertaken.

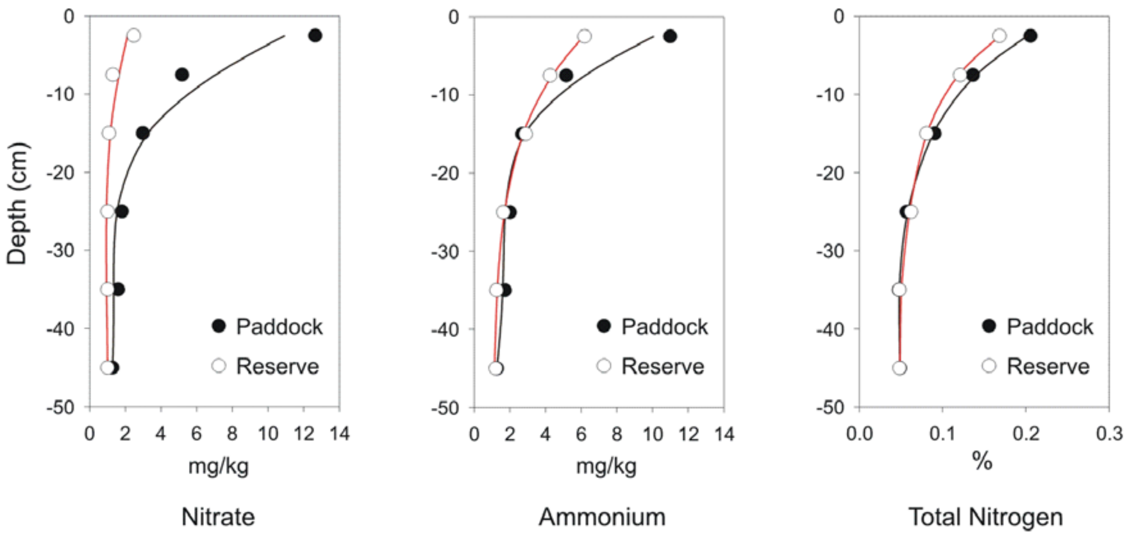

Fig. 2 Paddock and reserve differences for nitrate, ammonium and total nitrogen

The cation exchange capacity (Fig. 3) was consistent between reserve and paddock areas, but was variable between sites. This result showed that the site selection procedure was robust, and suggests that the soil type across the fence was the same for each site. Variation between sites was congruous with soil types of the survey which ranged between heavy clays and light sands. Further support for the validity of the site selection procedure was found with the analyses of phosphorus and sulphur. It appeared placement of the soil corers in the reserve away from fenceline effects effectively avoided any drift of fertilizer over the fence from aerial application and any phosphorus that may have migrated some distance from the fertilizer granule. Core placement within the paddock appeared to detect the phosphorus that had been applied there. A significant difference ($P \leq 0.05$) for phosphorus (Fig. 3) was evident for the 0-5 cm depth with the paddock having the higher value. The reverse was the case for10-20 cm and 20-30 cm where the reserve has a higher phosphorus value. These data are consistent with the available phosphorus uptake by deep rooted exotic pasture species. Available sulphur (Fig. 3) was higher in the paddock and was significant ($P \leq 0.05$) for 0-5, 5-10 and 10-20 cm. The spline analysis showed no convergence of the two profiles and this implied both a depth and treatment interaction.

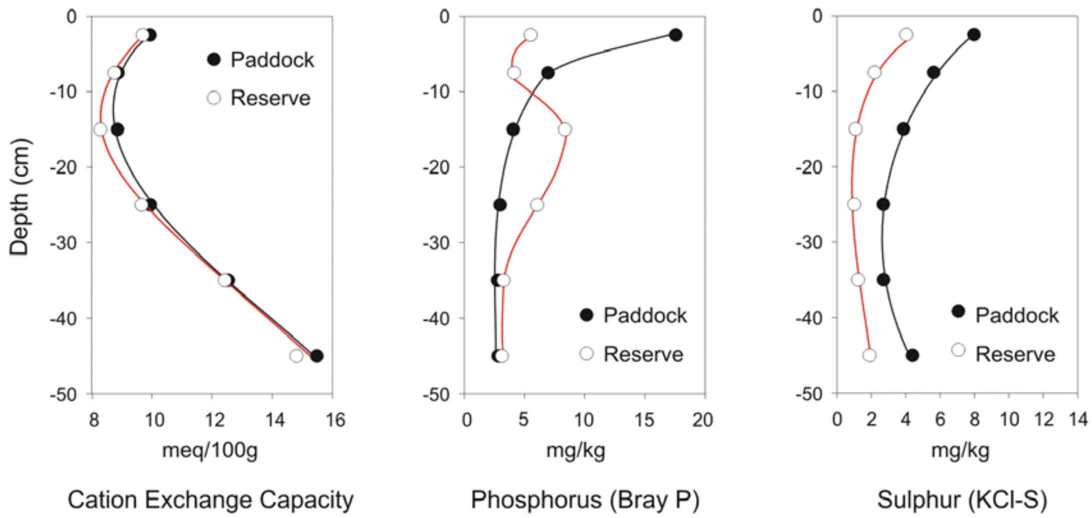

Fig. 3. Differences between paddock and reserve soils for cation exchange capacity, available phosphorus and available sulphur.

Conclusions

Results from this study clearly show that pasture management has accelerated soil acidification on the Northern Tablelands. Even though the degree of acidification is not high, at 0.1 of a unit for pH_{Ca}, when compared to nearly one unit (Williams, 1980) and 0.5 units (Chartres, 1990) for southeast Australian sites, acidification is still occurring and is cause for concern and action.

The next stage in the overall project is to identify those areas most at risk of soil acidification. Data from this paired-site study will undergo further statistical analyses; the data will also be assessed by soil type. These results will then be aggregated with the findings of an earlier survey that mapped acid soils of the Northern Tablelands. The original map will be upgraded and an at risk map developed. These maps will be useful extension tools that will show the problem areas and will assist in the recommendation of appropriate management options.

Appropriate management options that will be assessed include amelioration with lime. However, before the use of lime is advocated, the cost of lime and its effectiveness in reducing acidification needs to be fully researched for each area and each situation. The degree and extent of acidification on a property, as well as the soil type, need to be considered. Options such as growing more acid tolerant pasture species, limiting the use of legumes and ammonium fertilizers, rotational grazing, or a combination of these could prove more cost effective and yet be just as effective, production wise in an agronomical sense.

A principal step in improving the problem of soil acidification is communication with the land managers. Each farmer involved in the paired-site study will be given a report of the basic findings together with suggestions for management options. In this report, all test results will be listed without location. The farmer will be given his or her own results but will not know the results of neighbouring properties. Individual farmers may choose to ameliorate their land with lime; modify their grazing rotation; reduce the use of nitrogenous fertilizers or legumes; grow more acid-tolerant species; or do nothing. Alternatively, groups of farmers in an area could meet to discuss the findings of the report. Ideas for further research can be mooted, options for trials can be discussed and funding for these explored at this meeting. At this stage plans can be drawn up to help control the rate of acidification in the area.

Acknowledgments
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