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Scattered native trees and soil patterns in grazing land on the Northern Tablelands of New South Wales, Australia

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Abstract. Over large areas of south-eastern Australia, the original cover of native woodland has been extensively cleared or modified, and what remains is often characterised by scattered trees beneath which the ground-storey vegetation is largely grazed or otherwise managed. This study investigated the influence of scattered Blakely's red gum (*Eucalyptus blakelyi*) trees on both near-surface and deeper soil layers in temperate grazed pastures on the Northern Tablelands of New South Wales, Australia. A significant canopy effect was observed with elevated soil pH, carbon, and nutrient status inside the tree canopy indicating soil enrichment in a zone around the tree. This effect, however, was largely restricted to the surface (0–0.20 m) soil layers. Chloride concentrations were elevated near to trees but only in the deeper soil layers, suggesting that a modified water use and deep drainage mechanism occurred near the trees. Close to the tree, however, a significant acidification was observed between 0.40–0.60 m depth in the soil, without any obvious depletion in other soil element concentrations. It is concluded that this acidification provides strong evidence in support of a 'biological pumping' mechanism that has been proposed elsewhere. Key questions remain as to the management implications of these results, whether the subsurface acidification that was observed is common among native Australian trees, if it might be persistent through time, and if this might be a soil issue that requires management.

Additional keywords: scattered trees, soil pattern, soil acidity, soil carbon, soil nutrients.

Introduction

Over large areas of Australia, the original cover of native woodland has been cleared or modified, and what remains is often characterised by scattered trees beneath which the ground-storey vegetation is largely grazed or otherwise managed. These scattered trees, however, still provide a range of ecological functions (Gibbons and Boak 2002). Although individually they occupy a relatively small area, it has been estimated that cumulatively they cover as much as 20 million ha of Australian farmland (Reid and Landsberg 2000). Their combined influence on the landscape might therefore be profound, and as such, scattered trees have been referred to as 'keystone structures' in the Australian landscape (Manning *et al.* 2006).

One key effect that these scattered trees have on the landscape is a modification of the spatial pattern of surface soil properties in the immediate vicinity of the tree. For example, systematic patterns in soil chemistry and organic matter status have been observed under a range of tree species in Australia. Under eucalypts, soil pH is typically higher 'inside' compared with 'outside' the tree canopy (Ryan and McGarity 1983; Prober *et al.* 2002; Wilson 2002; Graham *et al.* 2004). Higher soil organic matter and nutrient contents have also been observed inside the canopy zone of a range of native Australian trees and shrubs (Chilcott *et al.* 1997; Dean *et al.* 1999; Facelli and Brock 2000; Facelli 2002; Wilson 2002; Graham *et al.* 2004)

and their presence would seem to create a distinct mosaic across the landscape with localised 'islands' of higher pH, organic matter, and nutrient status (Dean *et al.* 1999; Ozolins *et al.* 2001; Eldridge and Wong 2005). This modification of soil properties might therefore have significant implications for the management of soil condition across the extensive production landscapes of Australia.

Modification of soil chemistry by trees is often attributed to the redistribution of material from deeper soil layers to the soil surface within the tree's zone of influence. Noble *et al.* (1996) and Noble and Randall (1998, 1999a, 1999b) proposed a mechanism by which this 'biological pumping' might operate, whereby cations extracted from deeper soil layers are balanced by organic anions in the plant. These organic anions are subsequently deposited in litter at the soil surface under and around the tree, creating a zone where an increase in soil pH results. This process should presumably be balanced by other soil changes (e.g. acidification) in the root-zone deeper in the soil where protons are being added. However, few empirical data exist to illustrate soil patterns both spatially and with depth around single trees and therefore to confirm the operation of this process under native Australian trees. In order to understand the significance of single-tree effects on soils in production landscapes, there is a need to more fully understand the soil patterns and the effects of these trees on both surface and

subsurface soil conditions. Here, we seek to build on existing work that has examined soil spatial heterogeneity (e.g. Wilson 2002; Graham *et al.* 2004), and we present data relating to the change in soil properties both spatially and with depth under individual Blakely's red gum (*Eucalyptus blakelyi*) trees, in grazing lands on the northern Tablelands of New South Wales (NSW), Australia.

Materials and methods

Site selection

Twenty Blakely's red gum trees were selected from 3 grazed paddocks around Armidale, NSW. Armidale is located 375 km north of Sydney on the Northern Tablelands of NSW at an altitude of approximately 900 m (Fig. 1). The climate of the region is cool, temperate with a long-term average annual precipitation of 790 mm (Bureau of Meteorology 2006), which is slightly summer-dominant (108 mm in January and 56 mm in July). Mean maximum monthly temperature is 27°C in January and the mean minimum monthly temperature is in July at 0.3°C. Much of the native woodland cover in the region has been removed for the purpose of grazing sheep and cattle (Reid *et al.* 1997). Legumes and super-phosphate fertiliser are commonly used to improve pasture quality, but across the region, native trees commonly remain as scattered, 'paddock trees' beneath which are managed pastures dominated by native grasses.

Of the 20 individual trees selected, 10 were sampled on the University of New England, Newholme Field Laboratory, 5 km north of Armidale. The soils at this location were developed from Mount Duval Adamellite, a coarse-grained component of the New England Granites. Five trees were sampled at 'Rockvale' and a further 5 at 'Newby Park'. These 2 sites were 3 km north-east and 2 km south-west of Armidale, respectively. At Rockvale, soils were developed from New England metasediments of the Sandon Beds, while at Newby Park, soils were developed from a mixture of New England Metasediments (Sandon Beds) and Tertiary Basalt colluvium from the unclassified Armidale volcanics. The soils at Newholme and Rockvale were classified as Yellow Chromosols (Isbell 1996), and at Newby Park, soils were intergrades between Chromosols and Dermosols (Isbell 1996). Site details for each sampling location are provided in Table 1. Sampling sites were selected such that pastures beneath the trees were dominated by native grasses and had received only minimal fertiliser application. Previous work has demonstrated that while soil patterns around trees exist independent of animal 'camping', the concentration of animals around trees can affect the nature and magnitude of

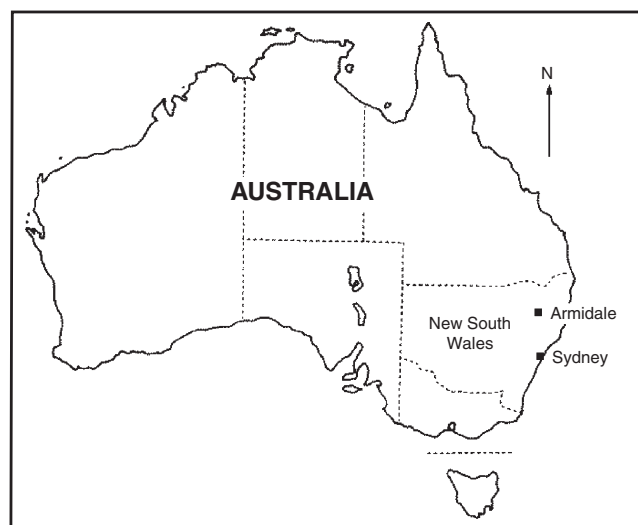


Fig. 1. Location map of NSW and Armidale.

the pattern in soil properties (Wilson 2002; Graham *et al.* 2004). For this reason, the trees at each sample site were selected around which no significant evidence of animal camping existed.

Soil sampling

At each tree, a transect was laid out on a bearing due north. The alignment of the transects was held constant in order to eliminate aspect as a confounding factor. Along each transect, soil samples were collected at 4 points arranged in proportion to the tree canopy size. Soils were collected adjacent to the tree stem (0.5 m), at half a canopy radius (0.5r), at the canopy edge (1r), and at a distance of 2 canopy radii (2r). This last sample point was located in the open paddock such that it was also at least 2 canopy radii from the next nearest tree to provide a sample point outside the influence of other trees. At each sample point, a soil core 0.80 m deep was collected using a coring device of 50 mm diameter. A core depth of 0.80 m was selected for practical reasons, this being the depth at which parent material was typically reached.

Soils were collected in discrete depth intervals (e.g. 0–0.05, 0.05–0.10, 0.10–0.20 m and then in 0.20-m increments to 0.80 m). Samples were stored in sealed plastic bags in cool, dark conditions and returned to the laboratory within 12 h of collection. Mineral soil samples were then dried at 40°C for 48 h and subsequently analysed at the INCITEC Werribee laboratory

Table 1. Site details for all sample locations including lithology (Department of Mines 1971) and soil type (Isbell 1996)

Location	Grid Ref	Lithology	Soil type	No. of trees sampled	Mean dbh (m)	Mean canopy radius (m)
Newholme	S30°25'20.87"; E151°39'21.67"	Granodiorite/granitic colluvium; Mount Duval adamellite	Yellow Chromosol	10	0.31	7.6
Rockvale	S30°29'20.13"; E151°41'54.35"	New England metasediments (Sandon beds)	Yellow Chromosol	5	0.23	5.46
Newby Park	S30°30'33.37"; E151°37'53.78"	New England metasediments (Sandon beds) and Tertiary basalt colluvium	Brown Chromosol/Dermosol	5	0.34	5.78

for pH (1 : 5 soil : 0.01 M CaCl₂), organic carbon percentage (Walkley and Black), nitrogen (Kjeldahl), and extractable phosphorus (Colwell). Calcium, magnesium, potassium and sodium were also analysed by ammonium acetate extraction and soil chloride concentration was determined in a 1 : 5 soil : water suspension.

Statistical analysis

Differences in soil characteristics between sites, depths, and distance from trees were explored using 3-way analysis of covariance (ANCOVA). The covariate 'depth' was fitted as a second-order polynomial. The data for soil characteristics carbon, phosphorus, nitrogen, calcium, and chloride were transformed using a fourth-root function before analysis to ensure normality and to satisfy analysis assumptions.

Results

Site, depth, and position on transect were all significant factors influencing differences in soil properties at the sites studied. Significant differences were found between sites (S) for all soil properties determined (except carbon and nitrogen), indicating that soil properties differed between the 3 locations sampled

(Table 2). Newby Park had lower mean pH, and Ca, Mg, and K contents (but higher mean soil phosphorus) than the other sites (Table 3). Mean soil carbon and nitrogen contents were not statistically different between sample sites, and although the mean value for both of these elements did appear to be considerably higher at Rockvale, the within-site variability in these soil properties was high at all depths (Table 3) and hence no statistical difference could be attributed.

Significant differences were also found with depth for all soil properties except pH. For soil C, N, P, Ca, and K, this resulted from a progressive decline in each parameter with increasing depth in the soil (Fig. 2). Conversely, soil magnesium, sodium, and chloride increased in concentration with increasing soil depth.

For most soil parameters (except pH and sodium), a significant difference was also found between the different positions along the transect. For soil C, N, P, Ca, Mg, and K, concentrations were higher in the surface soils at the 0.5 m point, adjacent to the tree (Fig. 2), compared with other points along the transect. A decrease in the concentration of each of these properties was then found with distance from the tree. For chloride, there was also a trend for larger concentrations

Table 2. *F*-values and associated probabilities for differences in soil constituents between sites, depths, and distance from tree

Significance level: **P* < 0.05, ***P* < 0.01, ****P* < 0.001

Source of variation	d.f.	Carbon	Nitrogen	Phosphorus	pH	Calcium	Magnesium	Potassium	Sodium	Chloride
Site (S)	2	1.5	2.6	74.6***	60.8***	65.5***	80.3***	121.9***	58.7***	275.2***
Depth (D)	2	947.8***	196.2***	73.8***	0.1	53.8***	130.4***	55.0***	105.5***	282.2***
Position on transect (P)	11	80.4***	47.6***	14.1***	3.2	23.7***	1.1	33.5***	0.4	33.7***
S × D	4	10.8***	13.7***	2.2	4.6**	9.5***	8.7***	7.4***	18.2***	156***
S × P	2	5**	55.4**	4.3*	1.2	5.0**	0.8	0.5	2.0	0.5
D × P	2	8.1***	9.9***	4.0*	9.3***	20.7***	10.0***	3.7*	1.4	7.5***
S × D × P	4	0.5	1.6	0.6	1.0	0.5	0.4	0.5	2.9*	0.9

Table 3. Mean values across all transects at each sample location

Values in parentheses are 1 s.e.

Sample location	Depth (m)	Carbon (%)	Nitrogen (%)	pH	P (mg/kg)	Ca	Mg (cmol ⁺ /kg)	K	Na	Cl (mg/kg)
Newholme	0–0.05	2.63 (0.42)	0.11 (0.11)	5.70 (0.06)	10.30 (0.50)	11.79 (1.39)	3.45 (0.50)	0.56 (0.30)	0.03 (0.04)	14.89 (0.83)
	0.05–0.10	1.49 (0.36)	0.09 (0.08)	5.52 (0.09)	5.61 (0.25)	7.79 (1.25)	2.15 (0.37)	0.29 (0.20)	0.03 (0.02)	11.05 (1.31)
	0.10–0.20	0.74 (0.16)	0.06 (0.06)	5.58 (0.07)	3.97 (0.21)	4.90 (0.68)	1.58 (0.08)	0.18 (0.15)	0.02 (0.01)	8.16 (0.61)
	0.20–0.40	0.42 (0.12)	0.04 (0.03)	5.64 (0.03)	3.64 (0.09)	3.44 (0.32)	1.64 (0.27)	0.13 (0.09)	0.04 (0.04)	7.27 (0.78)
	0.40–0.60	0.41 (0.08)	0.03 (0.01)	5.43 (0.04)	4.58 (0.27)	5.60 (0.33)	6.26 (0.54)	0.22 (0.04)	0.19 (0.02)	11.45 (1.24)
	0.60–0.80	0.33 (0.11)	0.05 (0.06)	5.49 (0.09)	6.09 (0.73)	6.37 (0.26)	8.45 (0.33)	0.24 (0.11)	0.31 (0.17)	19.66 (3.45)
Rockvale	0–0.05	4.19 (1.31)	0.34 (0.47)	5.10 (0.08)	18.81 (0.68)	11.44 (2.85)	3.14 (1.32)	0.81 (0.33)	0.06 (0.09)	0.00 (0.00)
	0.05–0.10	1.95 (0.61)	0.16 (0.19)	5.07 (0.08)	11.26 (0.66)	5.86 (1.27)	1.74 (0.44)	0.60 (0.23)	0.06 (0.04)	0.00 (0.00)
	0.10–0.20	0.94 (0.31)	0.07 (0.10)	5.15 (0.01)	7.67 (0.88)	4.21 (0.38)	1.47 (0.16)	0.42 (0.17)	0.09 (0.02)	0.00 (0.00)
	0.20–0.40	0.40 (0.27)	0.03 (0.06)	5.42 (0.09)	8.85 (0.64)	4.45 (0.33)	3.67 (0.29)	0.32 (0.18)	0.46 (0.04)	9.22 (1.75)
	0.40–0.60	0.30 (0.22)	0.03 (0.09)	5.45 (0.11)	10.85 (0.73)	5.93 (0.21)	7.54 (0.19)	0.33 (0.08)	1.13 (0.17)	23.74 (3.74)
	0.60–0.80	0.22 (0.28)	0.02 (0.09)	5.54 (0.19)	7.63 (1.00)	5.55 (0.31)	7.39 (0.61)	0.28 (0.12)	1.17 (0.34)	29.98 (4.64)
Newby Park	0–0.05	2.68 (0.30)	0.17 (0.21)	4.93 (0.05)	25.34 (0.13)	6.09 (0.86)	1.19 (0.20)	0.25 (0.18)	0.07 (0.03)	0.00 (0.00)
	0.05–0.10	1.60 (0.22)	0.11 (0.21)	4.96 (0.10)	7.77 (0.28)	4.62 (0.83)	0.82 (0.16)	0.14 (0.11)	0.05 (0.02)	0.00 (0.00)
	0.10–0.20	0.97 (0.19)	0.05 (0.20)	5.08 (0.10)	5.82 (0.15)	3.52 (0.73)	0.67 (0.08)	0.08 (0.12)	0.04 (0.03)	0.00 (0.00)
	0.20–0.40	0.44 (0.05)	0.06 (0.01)	5.10 (0.11)	6.61 (0.47)	2.83 (0.44)	1.25 (0.20)	0.08 (0.06)	0.08 (0.21)	13.19 (1.16)
	0.40–0.60	0.33 (0.12)	0.05 (0.03)	4.90 (0.08)	11.07 (0.32)	2.82 (0.32)	2.50 (0.35)	0.10 (0.02)	0.19 (0.34)	16.13 (1.66)
	0.60–0.80	0.21 (0.04)	0.04 (0.09)	4.92 (0.03)	14.87 (0.11)	1.96 (0.22)	2.60 (0.22)	0.09 (0.02)	0.12 (0.15)	17.22 (2.59)

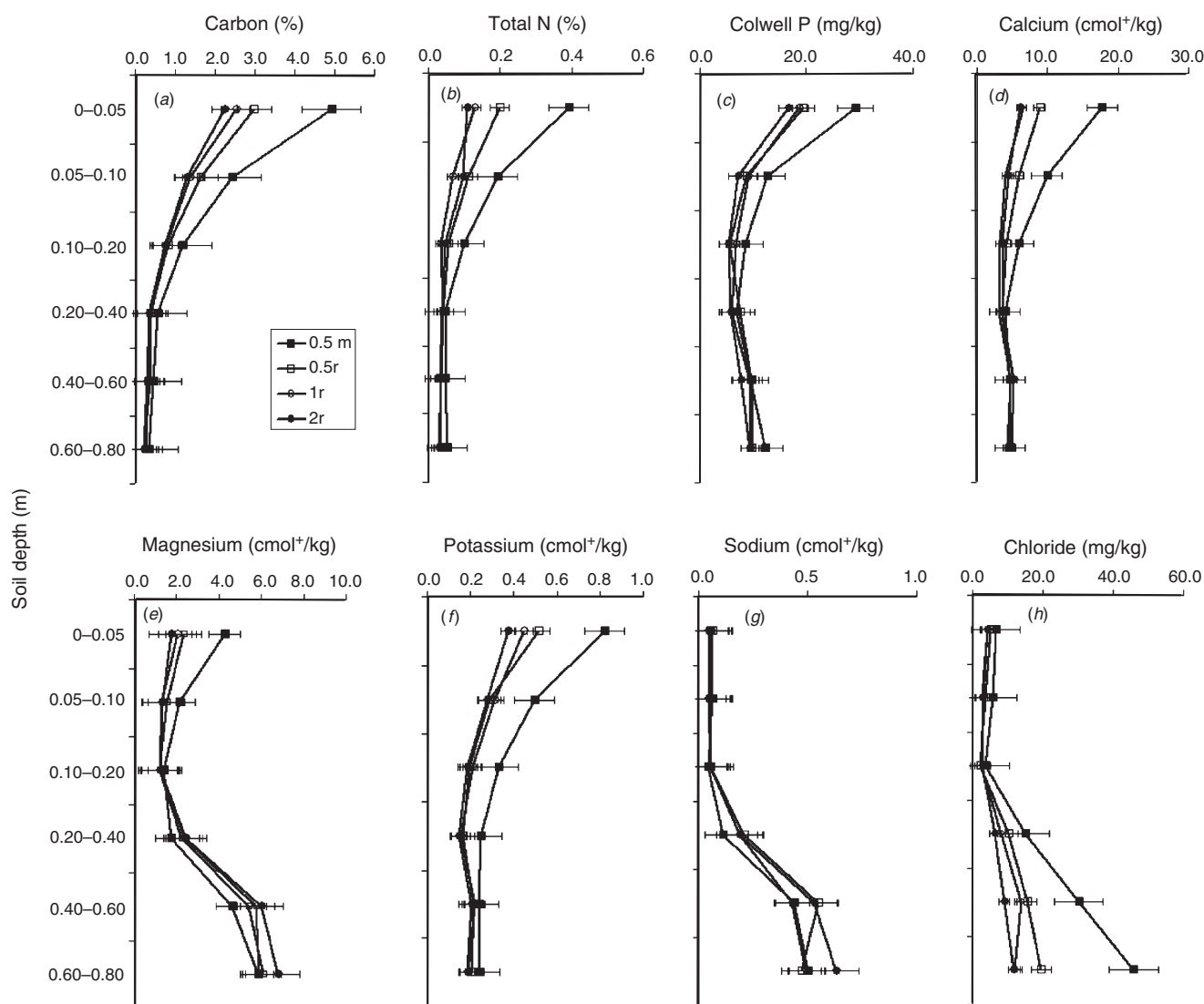


Fig. 2. Profile diagrams for average soil carbon, nitrogen, phosphorus, calcium, and chloride contents at each transect point under *E. blakelyi*, Armidale, NSW. (Error bar = 1 s.e.)

near to the tree with a decline with distance from the tree. However, for this property, the trend was only observed in the deeper soil layers. Soil sodium had similar concentrations in the soil irrespective of position on the transect. For soil pH there was no significant interaction with depth or position on the transect.

A range of interactions were also found between site, depth, and position on the transect for the various soil properties determined (Table 2). For example, a significant interaction was found between site and depth for all properties except P, indicating that for the majority of the soil properties determined, the values for each soil parameter found at the various depths in the soil profile differed between sites. A significant interaction was also found between site and position for C, N, P, and Ca. This result and the site \times depth interaction reflected differences in the magnitude of values at the various sites (Table 3). There was also a significant interaction between depth and position for

all properties except sodium. For soil C, N, P, Ca, Mg, K, and Cl this interaction reflected larger concentrations in the surface soils close to the tree (Fig. 2) and therefore a greater degree of curvature down the profile for these soil properties at that position on the transect. However, it is apparent from the profiles in Fig. 2 that this difference in profile form was largely restricted to the 0–0.20 m soil layers for most properties (and below 0.40 m in the case of Cl).

For soil pH, quite different profile curves were generated depending upon the position on the transect (Fig. 3a). At the points furthest from the tree (2r) surface soils were more acid than under the tree canopy. A slight further acidification was detected at the 0.05–0.10 m depth at this position on the transect, but pH increased thereafter with increasing depth in the soil profile. In the surface layers near to the tree, however, soil pH was higher than other transect positions and remained constant with depth to 0.20–0.40 m. Adjacent to the tree, soil pH was

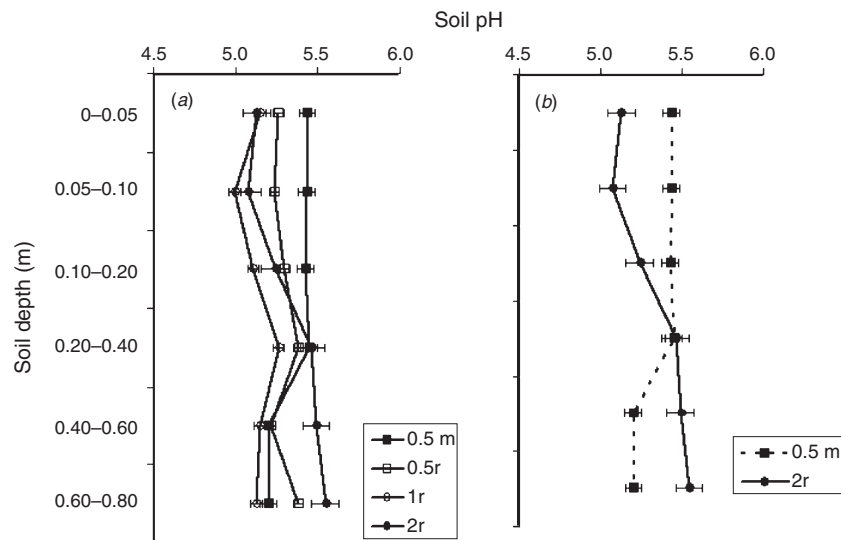


Fig. 3. Profile diagrams for average soil pH for (a) all transect points and (b) adjacent and 2r points only. (Error bar = 1 s.e.)

significantly lower (by up to 0.4 pH units) at 0.40–0.60 m. For the purposes of illustration, Fig. 3b separates the 2 end points of the transects (0.5 m and 2r) and shows the quite different form of these profiles. The 2 other transect points had curves intermediate between these extremes. The difference in pH profile form at the different positions on the transect, in effect, masked any difference in overall mean pH change with depth.

Discussion

Despite differences in the magnitude of some soil properties between sample sites that reflected differences in lithology, some consistent patterns were found in soil spatial pattern and depth profile across the sites studied. For example, all sites showed a significant canopy effect where the trees influenced the spatial pattern of soil properties. Surface soil pH was higher near to the tree, and for most of the other soil properties determined, larger concentrations were found in surface soils 'inside' compared with 'outside' the tree canopy. This result confirms the findings of similar work elsewhere (e.g. Ryan and McGarity 1983; Chilcott *et al.* 1997; Prober *et al.* 2002; Wilson 2002; Graham *et al.* 2004) and suggests that trees in these grazed landscapes are the focus around which higher soil carbon and nutrient accumulation takes place. This canopy effect was, however, largely limited to the surface (0–0.20 m) layers. Below this depth, most of the soil properties determined declined with increasing depth but showed little difference between points on the transect. These results support the notion that the presence of trees in these grazing landscapes promotes 'patches' or 'islands' (Dean *et al.* 1999) of high organic matter and nutrient accumulation, although this enrichment does not extend to any great depth in the soil.

Some significant statistical interactions were found between the various soil properties and both site \times depth and site \times point on transect. In both of these instances, however, these

interactions represent site differences in the magnitude of the various soil properties and can again be attributed to differences in lithology. Trends and patterns in the data were similar across all lithologies.

Depth profile patterns for soil pH, sodium, and chloride content were of a different character to those observed for other soil properties. For soil sodium content, no significant difference existed between any of the transect points, which indicates that soil sodium is probably not accumulated or redistributed to any great extent by the eucalypt trees studied. For chloride, an accumulation did occur close to the trees but only in the deeper soil layers. Chloride profiles provide a useful indication of historic deep drainage through the soil (Young and McLeod 2001) and it is possible that the differences observed between the different points along the transects reflect a greater efficiency in water use around the trees, limiting deep drainage, and hence, flushing of salt from the deeper soil layers. Detailed analysis of this result is beyond the scope of the current work. Nevertheless, the observed pattern would seem to confirm that trees in these landscapes have a function in moderating the liberation and release of chloride salts from the deeper soil profile (Young and McLeod 2001).

The pattern of soil pH with depth was, however, quite different to the other properties determined. Lower soil pH was found in surface soils 'outside' the tree canopy and this is a common feature in grazed pastures on the Northern Tablelands. In addition, a zone of increased acidity was observed at 0.05–0.10 m depth in the soils 'outside' the tree canopy. The processes responsible for this soil acidification have been discussed widely elsewhere and probably reflect livestock production, the export of soil nutrients in product removal, and increased nitrate leaching from urine and legumes in these pastures (Helyar and Porter 1989; Robinson *et al.* 1995; Lockwood *et al.* 2003; Condon *et al.* 2004). Under the tree canopy, however, surface soils had a higher pH, and a zone of increased soil acidity was found at depth in the soil (0.40–0.60 m) at the sampling

point closest to the tree. This subsurface acidification was absent outside the tree canopy.

It has been proposed in the literature (e.g. Noble *et al.* 1996; Noble and Randall 1999a, 1999b) that trees operate as 'biological pumps' extracting cations from depth in the soil, which is balanced by the manufacture of organic anions by the tree to maintain charge balance. These organic anions are redistributed in the tree and deposited at the soil surface in litter fall, causing a rise in surface pH. Graham *et al.* (2004) confirmed that the ash alkalinity of scattered trees *in situ* did have a significant effect on surface soil pH, although this effect differed between tree species. Litter chemistry would therefore certainly appear to affect soil pH. Noble *et al.* (1996) and Noble and Randall (1999a, 1999b) further proposed that, as a balancing process, trees will induce acidity at depth, though few empirical data have been presented to date to support this assertion. Results presented here would appear to lend support to the presence of such a mechanism.

Acidification at depth in the soil under the tree was not reflected in any measured depletion of cation or anion concentration at these depths. The eucalypts studied in these grazing landscapes would therefore seem to raise pH at the soil surface with a balancing process of acidification in the deeper soil layers but without any significant associated soil nutrient depletion. This is probably due to the relatively large quantities of cations present in the deeper soil layers such that removal by the tree makes little impact on the bulk quantity in the soil. Nevertheless, acid addition by the tree at this soil depth would appear to be sufficient to produce a significant impact on soil pH.

It has been suggested that the pattern of soil properties around trees in grazed paddocks is the result of animal camping and the preferential addition of material to the soil in dung and urine (e.g. Hilder 1964; Comino 1983). However, Wilson (2002) and Graham *et al.* (2004) have demonstrated that soil patterns associated with scattered trees occur independent of the presence or absence of animal camping. At the sites studied here, no evidence could be seen of significant animal camping at the trees studied, and it seems clear that the patterns observed result from the influence of the trees themselves.

Amelioration of soil acidity and accumulation of organic matter and nutrients in surface soils under scattered eucalypt trees might therefore be considered to have a positive effect in grazing landscapes in northern NSW by helping to maintain soil condition. Although we concede that this study has focused on only one eucalypt species, our results would suggest that the presence of trees locally enhances or at least conserves soil condition compared with open paddocks, so that their incorporation within production landscapes would have tangible benefits. However, we have also provided evidence for the 'biological pumping' mechanism that has been proposed, and it would appear that enrichment and pH rise at the soil surface is indeed balanced by subsurface acidification beneath the tree. Whether or not the subsurface acidification observed constitutes soil 'degradation' is uncertain, since it takes place at some considerable depth in the soil and is somewhat isolated from the surface soil, which is more important to plant growth. The effect is also of limited spatial extent and associated only with the point adjacent to the tree.

Several key questions remain with respect to the management implications of these results. These include: (i) do these processes and patterns with depth occur under many or all the common native tree species in the region; (ii) is the effect less or more intense under specific species; (iii) does the subsurface acidification have any tangible effect on production; and (iv) how persistent might this subsurface acidification be through time and might soil management strategies be required to address this issue? These questions are currently the subject of further research.

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