Influence of scattered paddock trees on surface soil properties: A study of the Northern Tablelands of NSW

By Brian Wilson

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Summary Surface soil conditions were assessed under three tree species on a property near Armidale on the Northern Tablelands of NSW. In both a stocked and adjacent destocked paddock, five trees each of three eucalypt species: *Eucalyptus melliodora*, *Eucalyptus blakelyi* and *Eucalyptus nova-anglica*, were selected. Soil samples were collected (depth 0–10 cm) along transects 20 m in length running from beneath the tree canopy progressively outwards into the open paddock. Six additional transects were also sampled outside the influence of the trees. Soil properties at a distance from the trees differed little between the stocked and destocked paddock with only a slight acidification in the stocked paddock. However, soil properties around the scattered trees showed considerable variation between stocked and destocked equivalents and most notably in a systematic pattern with distance from the trees themselves. For example, bulk density increased significantly, whereas soil pH, carbon, nitrogen and extractable phosphorus contents all decreased significantly with distance from the trees. However, stocking and camping had modified some of these soil properties. In the stocked paddock, the systematic change in nitrogen and phosphorus with distance from the trees was less clear and the degree of dispersion of the data was largest at the most heavily camped site. In this paddock, bulk density was also generally higher whereas pH, carbon and nitrogen contents were lower compared with the destocked equivalent. Extractable phosphorus content was also higher around the trees in the stocked paddock especially where camping activity was most intense. It is concluded that, although animal camping can modify their effects, scattered trees have a beneficial effect on soil properties and in this respect they have value in the grazing system from a soil conservation perspective.

Key words *grazing systems, scattered paddock trees, soil condition, soil nutrient status, soil pH, surface soils.*

Introduction

As a result of extensive vegetation clearance for agriculture and grazing, scattered native trees are common in the landscape of NSW. There is, however, continued and increasing pressure from landholders for the removal of these trees in order to improve efficiency by simplifying cultivation practices or simply to 'tidy up' the agricultural landscape. However, these scattered trees might play an important role in the rural landscape (Ozolins *et al*. 2001).

For example, the ecological role and habitat value of scattered paddock trees has been demonstrated (Kitching & Allsop 1997; Law *et al*. 2000; Majer & Recher 2000). Their function in limiting deep drainage and, hence, reducing catchment dryland salinity has also been shown (e.g. Zhang *et al*. 1999) while production benefits have been associated with the presence of scattered trees on farmland (Bird *et al*. 1992; Gregory 1995; Reid & Thompson 1999; Walpole 1999).

Trees have been shown to have a marked effect on the soils in their immediate vicinity both in Europe (Skeffington 1984; Beniamino *et al*. 1991; Bochet *et al*. 1999) and North America (Zinke 1962; Boettcher & Kalisz 1990), where results have typically shown higher soil organic matter and nutrient contents (e.g. phosphorus and nitrogen) in the soils around trees, which diminished with distance from the tree. In Australia, some work has demonstrated that the addition of tree litter to soils can raise pH while altering soil chemistry as a consequence of the decomposition process and ash alkalinity of the litter (e.g. Noble *et al*. 1996; Yan *et al*. 1996). However, work in Australia on the effects of trees, in situ, on soil properties is limited (Ryan & McGarity 1983; Sinclair 1983) and especially so in grazing systems.

It is well known that trees in grazed systems can attract livestock in 'camps' that are preferentially enriched with organic matter and nutrients (Taylor & Hedges 1984). However, the extent to which such camping might augment or alter the nature and pattern of soil properties associated with the trees is not entirely clear.

The present paper describes a small-scale study that was undertaken at the

University of New England, Newholme Field Laboratory near Armidale in NSW in October 1999. The investigation took place in a stocked (4 dry sheep equivalents (DSE)/ha) paddock and a destocked (since 1988) paddock for which detailed records of prior management existed. The aim of the study was to determine the effects of trees, in situ, on the nature and pattern of surface soil properties in this environment and to assess the extent to which stock camping might augment or influence these effects.

Site descriptions

Study sites were located at the University of New England, Newholme Field Laboratory. Newholme is located on the Northern Tablelands of New South Wales 10 km north of Armidale (Fig. 1). The climate is cool, temperate and the summer dominant rainfall has an annual average typically around 800–900 mm. As with much of the Tablelands, most of the native woodland cover at Newholme has been removed for the purpose of grazing sheep and cattle (Reid *et al*. 1997) and most of the property has received super-phosphate applications.

Soils on all sites were derived from granite or granitic colluvium and were mainly Yellow Soloths/Podzolic soils (Stace *et al*. 1968; the soils have more recently been classified as Eutrophic Yellow Chromosols after Isbell 1996). These soils are typically mildly to moderately acid near to the surface with near-neutral subsoils and have relatively low intrinsic nutrient value.

Sample sites were located within 'Cameron's Paddock' and 'Rosemary's Lot' (Fig. 1). Prior to 1988, these two paddocks were, in fact, one and managed under the same grazing regime at approximately 4 DSE/ha. Single super-phosphate was applied in 1965 at a rate of 125 kg/ha but no further fertilizer application has occurred since that time. In 1988, Rosemary's Lot was fenced off from the larger paddock and stock were excluded. For this reason, Rosemary's Lot will hereafter be referred to as the 'destocked' site although it is acknowledged that sheep grazing occurred prior to 1988 and that grazing by macropods and rabbits still takes place within the paddock. Sheep grazing has continued to the present day in the adjacent Cameron's paddock at a constant rate of approximately 4 DSE/ha.

In both paddocks, some scattered trees remain. Tree regeneration is entirely absent in the stocked paddock and, although some regeneration has taken place in the destocked paddock, both paddocks still have large areas of open grass without tree cover. In each paddock, three tree species were selected for study, namely Yellow Box (*Eucalyptus melliodora*), Blakely's Red Gum (*Eucalyptus blakelyi*) and New England Peppermint (*Eucalyptus nova-anglica*). These species are common on the northern Tablelands of NSW and are typical of the isolated tree

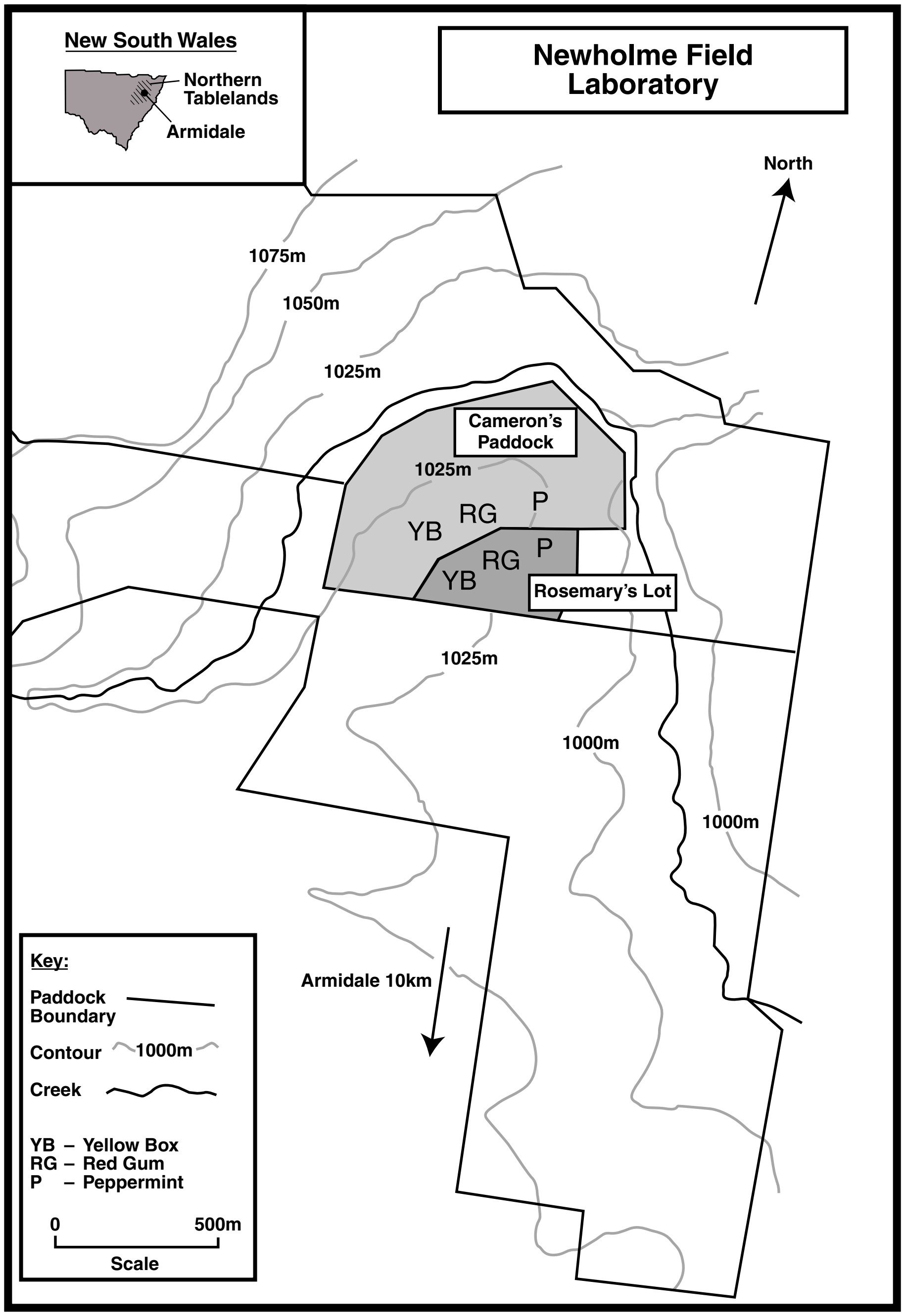


Figure 1. Location map showing Newholme Field Laboratory and the sample sites, Camerons Paddock (stocked) and Rosemary's Lot (destocked).

species that remain in grazed paddocks in this region. Each of the species occupied a distinct position on slopes with Yellow Box on upper slopes, Red Gum on mid-slopes and Peppermint in the lower slope positions.

Methods

Sample design

The six paired sample locations (stocked *vs* destocked) covered a range of slope positions ranging from 1010 to 1030 m altitude, but they each had a common easterly aspect and gentle slope angle (0–5°). Five individuals of each tree species were selected in each paddock (Table 1) and a transect sampling scheme was implemented. At each tree, a 20 m transect was laid out on a bearing of 130° from north, along which 10 samples were taken at 2 m intervals. One further 20 m transect was also laid out in the open paddock near each tree species ($n = 6$) but at least 50 m from the nearest tree and sampling was carried out on the same design in order to assess soil condition outside the influence of trees.

Soil sampling

Soils were sampled to a depth of 10 cm from the mineral soil surface following the transect sample design outlined above. Soil samples were collected using a stainless steel coring device of 30 mm diameter, which extracted undisturbed soil cores. Intact soil cores were stored in cool dark conditions until they were returned to the Department of Land and Water Conservation laboratory in Armidale. Soils were then dried at 40°C and crushed to pass through a 2-mm sieve.

Soil analysis

Bulk density (g/cm^3) was determined (corrected for coarse material) for each soil sample and soils were then analysed by INCITEC Analysis Systems at their Brisbane soils analysis laboratory. Soil pH was determined in $CaCl_2$ in a 1:5 suspension and read using a combination electrode. Soil carbon content was determined using the Walkley and Black method using H_2SO_4 and $K_2Cr_2O_7$, carbon content being measured colorimetrically. Total nitrogen content was determined using the Kjeldahl digestion method and extractable phosphorus using the Colwell extraction using $NaHCO_3$ and measurement colorimetrically.

Camping

The degree to which individual trees were subject to animal camping was assessed by counting the number of dung pellets per m^2 at four points along each transect, namely 2 m, 5 m, 10 m and 20 m. The figures were then converted to equivalent mass of dry material by empirical measurement and averaged across the transect. The quantity of dung was also assessed in the additional sampling sites in the open paddocks. These measures provided a relative indication of animal camping intensity at each sample location.

Statistical analysis

For each location, soil data from the open paddocks were first compared using one-way ANOVA to determine the degree of difference between stocked and destocked paddocks outside the influence of trees. The nature and pattern of soil properties from samples along the transects were then assessed. The transect data were found to have a log normal distribution and for statistical analysis these data were log transformed to satisfy normality assumptions. The significance of difference between stocked and destocked paddocks was then determined using a one-way ANOVA. The significance of change in soil properties with distance from the tree was determined using a Pearson's Product Moment Correlation on the log-transformed data.

Results

Soils in the open paddocks

Table 2 provides mean values for the mass of dung (mainly sheep in the stocked and macropod in the destocked paddock) along with values for the various soil properties determined in the paddocks outside the influence of trees at each sampling location. Soils in the open paddocks of both the stocked and destocked sites were largely very similar and were of mild to moderate acidity with low organic matter content and relatively low nutrient status. Soil bulk density was similar in all the open paddocks at around 1.1–1.2 g/cm^3. Carbon and extractable phosphorus contents were also largely similar in the two open paddocks. However, soil pH and total nitrogen were generally significantly higher, whereas the quantity of dung was lower, in the destocked paddock, with the exception of the Peppermint site, where these properties were again similar in both paddocks.

The pattern of soil properties around trees

The mass of dung and, hence, the intensity of animal camping, was generally significantly higher around the trees (Table 3) compared with the open paddocks

Table 1. Summary data from trees in stocked and destocked paddocks

	Tree species	Mean dbh (m; $n = 5$)	Mean tree height (m; $n = 5$)	Mean approximate canopy radius (m; $n = 5$)
Stocked	Yellow Box	0.65	19.2	8.0
	Red Gum	0.63	18.3	7.6
	Peppermint	0.46	12.9	4.8
Destocked	Yellow Box	0.65	20.9	7.5
	Red Gum	0.50	19.1	7.8
	Peppermint	0.44	16.6	5.2

dbh, diameter at breast height.

Table 2. Comparison of mean soil properties in open paddocks

	Stocked Open paddock	Destocked Open paddock
Mass of dung (g/m²)		
Yellow Box	6.7**	1.8
Red Gum	5.0*	4.2
Peppermint	1.7	2.1
Bulk density (g/cm³)		
Yellow Box	1.16*	1.12
Red Gum	1.23	1.24
Peppermint	1.18	1.19
pH		
Yellow Box	5.15**	6.15
Red Gum	5.12**	6.07
Peppermint	5.32	5.43
Organic carbon (%)		
Yellow Box	1.15*	1.30
Red Gum	1.06	1.03
Peppermint	1.10	0.99
Total nitrogen (mg/kg)		
Yellow Box	1236**	1452
Red Gum	1071**	1196
Peppermint	998	966
Phosphorus (mg/kg)		
Yellow Box	6.30	6.50
Red Gum	5.30	4.30
Peppermint	4.20	4.80

*Significantly different from destocked equivalent at $P < 0.05$; **significantly different from destocked equivalent at $P < 0.01$.

Table 3. Average mass of dung pellets along transects in stocked and destocked paddocks

	Mass of dung (g/m2)	
	Stocked	Destocked
Yellow Box	40.1**	14.0
Red Gum	22.8**	12.7
Peppermint	2.1	1.1

**significantly different from destocked equivalent at $P < 0.01$.

(Table 2). However, the quantity of dung found around the trees differed considerably between the stocked and destocked paddocks. Camping (mainly sheep) was clearly most intense in the stocked paddock in all cases. This was especially so at the Yellow Box location in the top-slope position. Significant camping (mainly macropod) was also evident at the top-slope position around the Yellow Box in the destocked site. In both cases, the mass of dung present and, thus, the presumed intensity of camping declined downslope. Only limited evidence of animal camping was found around any of the Peppermint trees.

The pattern of soil properties associated with the trees in the paddocks is illustrated in Fig. 2a–c. In this figure, soils data are plotted against log distance in a series of transect diagrams with probability values indicating the significance of the change in each soil property with distance from the tree. The pattern in soil properties around the trees was very striking and appeared to change systematically with distance from the tree stem. For example, soil bulk density increased significantly ($P < 0.01$) with distance from each tree species in both paddocks. For pH and soil carbon content, values declined significantly with distance from each tree, although for Peppermint at the destocked site the pattern for pH was poorly defined and was not significant with distance from the tree.

Both total nitrogen and extractable phosphorus followed a similar pattern with a significant decrease with distance from trees in the destocked paddock. However, in the stocked paddock, no significant pattern was found with distance from the tree for total nitrogen under the most heavily camped (Yellow Box) site. For phosphorus, no significant pattern was found under any of the tree species in this paddock.

Comparing transect data between stocked and destocked paddocks, some significant and important differences were found. Soil bulk density was generally higher and soil pH significantly lower in the stocked paddock. Soil carbon content was also significantly lower in the stocked paddock under and around the Red Gum and Peppermint trees, although around the Yellow Box trees values were similar between stocked and destocked paddocks (Fig. 2b). The pattern for soil nitrogen content was mixed but was generally similar in the two paddocks or slightly lower in the stocked paddock. Extractable phosphorus content was consistently and significantly higher around the trees in the stocked paddock and especially so under Yellow Box (note larger scale in stocked Yellow Box phosphorus graph in Fig. 2c).

Discussion

The results reported are from a relatively small-scale study. Although the study lacked extensive replication and can only provide preliminary insights, some significant and informative results were found with regard to the in situ effects of scattered paddock trees on surface soil properties.

When soils outside the influence of trees were compared in the two adjacent (stocked and destocked) paddocks, they were found to be broadly similar. The key difference between the soils was the lower pH and lower concentration of nitrogen in the soils of the stocked paddock. This might suggest a degree of acidification in the soils under active sheep grazing that might be linked with nitrogen mineralization and leakage and such processes

(a)

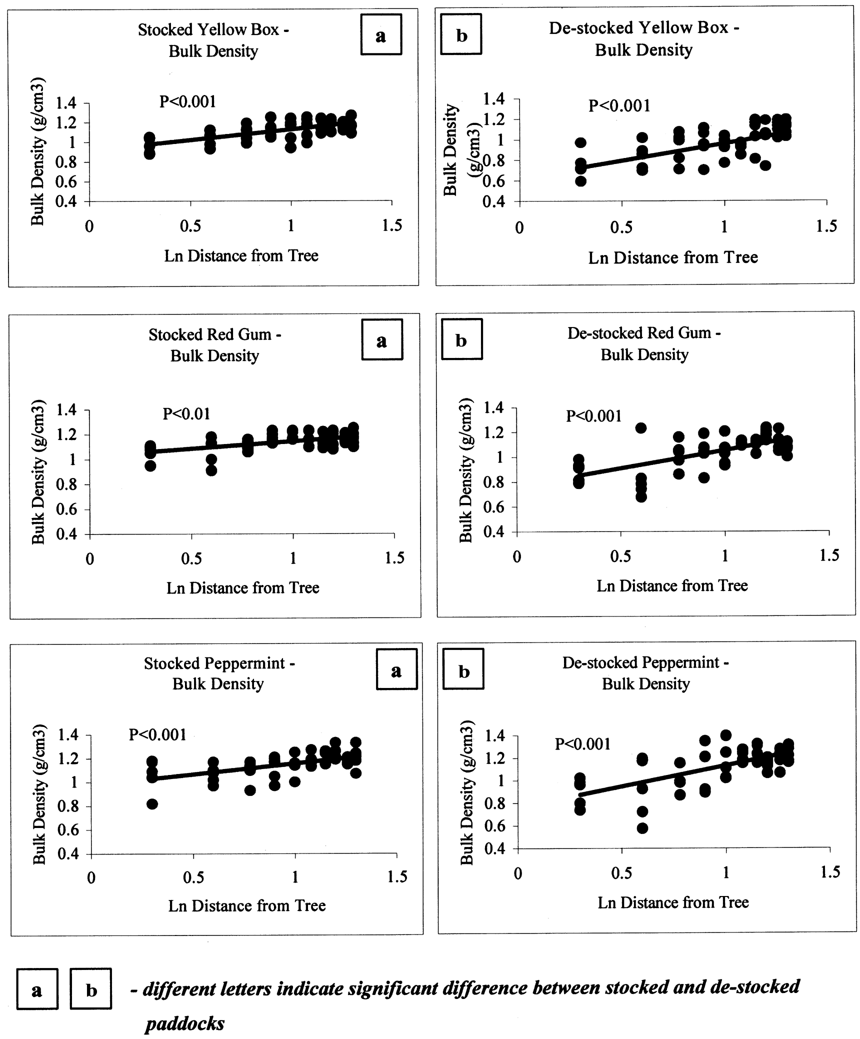


Figure 2(a). Bulk density determined at Newholme plotted against log distance from trees.

have been discussed at length in the literature (Helyar & Porter 1989; Conyers *et al.* 1995; Conyers *et al.* 2000).

Around the trees, the accumulation of dung and, hence, the intensity of animal camping, was largest in the stocked paddock and this was especially true around the Yellow Box trees. However, it is interesting that a significant accumulation of macropod dung (although smaller in overall quantity) was found in the destocked paddock and this, again most notably, was around the Yellow Box trees that occupied the top-slope location. In the stocked paddock, this pattern might be explained by the common observation that sheep preferentially locate their nocturnal camps in elevated positions (Hilder 1964; Taylor *et al.* 1984; McCaskill & Cayley 2000). It might also be speculated from the data presented that macropods exhibit similar behaviour, although they do not appear to actually share camps with sheep.

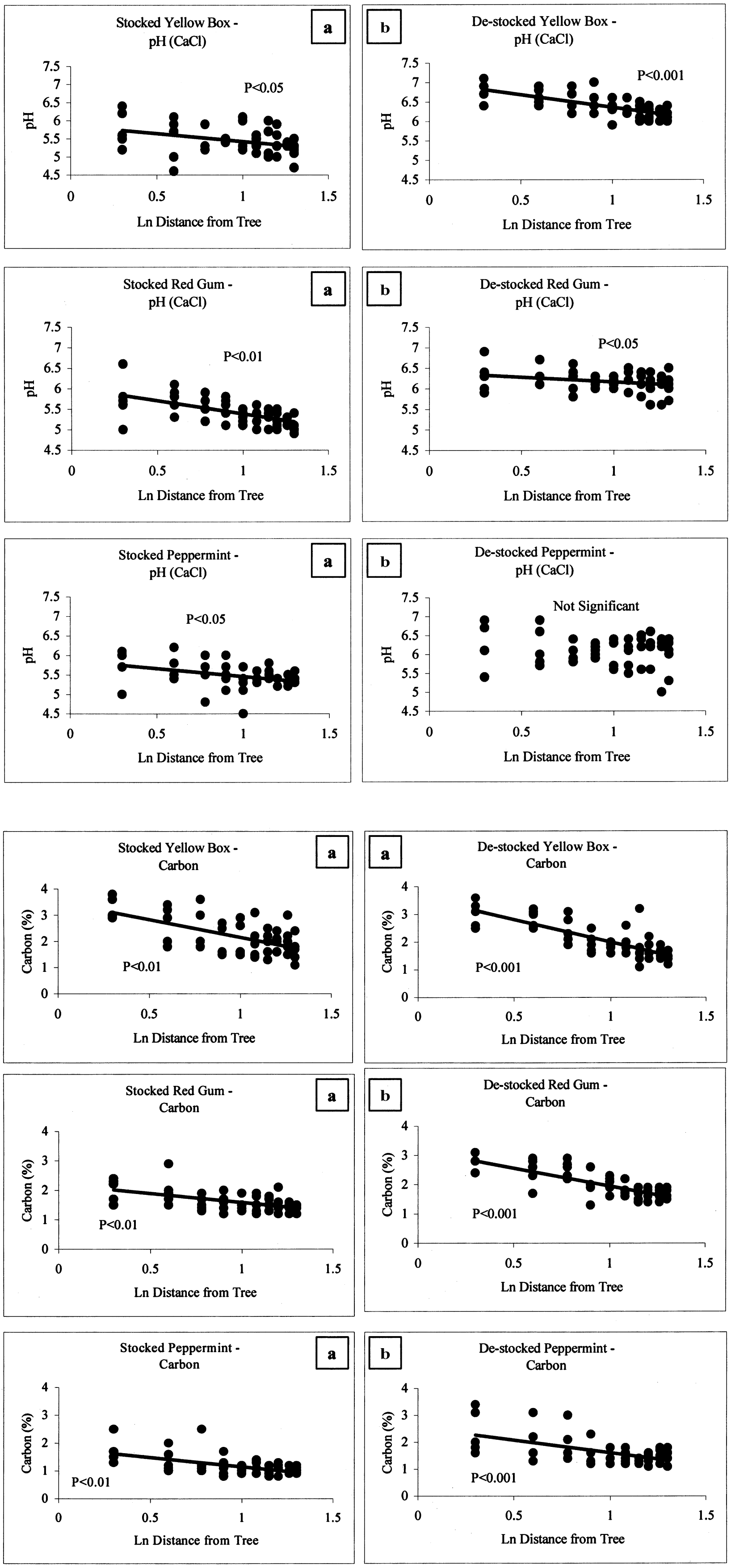
Soil properties around the scattered trees in the paddocks showed some considerable variation between stocked and destocked equivalents but, most notably, soil properties varied systematically with distance from the trees themselves (Figs 2a–c) Bulk density increased while soil carbon content decreased with distance from each of the tree types in both paddocks. This is a pattern that has frequently been found around trees (Crampton 1982; Ryan & McGarity 1983; Sinclair 1983; Burrows & Burrows 1992) and is thought to result principally from the increased root activity and larger quantities of litter and organic matter added to the soil surface under trees.

However, comparing the two paddocks, bulk density was consistently and significantly higher and carbon content lower in the stocked paddock (Fig. 2a). Higher bulk density can indicate a more compact soil and animal trampling probably contributed to this in the stocked paddock while lower soil carbon and organic matter levels might also contribute. The lower carbon contents might result from reductions in surface grass cover, root density and litter inputs in the stocked paddock. Much of the organic matter on the soil surface in the stocked paddock was in the form of slowly decomposing animal dung and only where very large accumulations of dung occurred (e.g. under Yellow Box) did the two paddocks have similar soil carbon contents.

Soil pH declined with distance from the trees in each of the paddocks studied (Fig. 2b). This soil change might result from a variety of processes, although the relative importance of these is not yet entirely understood. It has been suggested that trees act as 'biological pumps' and that the addition of tree litter to the soil surface can modify surface soil pH through the oxidation of organic anions in the litter that balance excess cation uptake by the trees (Noble *et al.* 1996). However, evidence to support the assumption that significant quantities of cations and anions are drawn from deeper soil layers is, in fact, limited. Indeed, some work (Harrison *et al.* 1988) has demonstrated that some tree species draw the majority of their mineral nutrients from the near-surface soil layers and that depletion of the subsurface layers need not take place. Trees may, therefore, conserve a higher soil pH by cycling cations/anions more efficiently than elsewhere in the paddock, rather than necessarily depleting the subsurface soils. More research is needed to determine the details of these processes and cycles.

The concentrations of both nitrogen and phosphorus in soils also diminished with distance from the trees (Fig. 2c). The zone beneath the trees would therefore seem to have a relatively high fertility by comparison with the surrounding paddock.

(b)



This will undoubtedly be due to nutrient relocation in dung where animal camping takes place. However, the pattern was especially clear in the destocked paddock, which might suggest that a range of other processes were operating. For example, the ability of a tree (due to its larger root mass) to explore a larger volume of the soil and scavenge nitrogen and phosphorus, perhaps with the aid of mycorrhizal fungi (Tommerup & Bougher 2000) might be a key process. Nutrient accumulation resulting from through-fall, stemflow and the washing of windblown material from leaf surfaces during precipitation events might also contribute (Gersper 1970; Gersper & Hollowaychuk 1970a,b; Gersper & Hollowaychuk 1971; Ford & Deans 1978; Nilsson *et al.* 1982; Duijsings *et al.* 1986; Leys & McTainsh 1999). Trees probably also attract invertebrates, birds and mammals, which import nitrogen and phosphorus to the site and deposit it around the tree.

In the stocked paddock, the systematic change in nitrogen and phosphorus with distance from the trees was less clear and the degree of dispersion of the data was largest where dung accumulation was greatest (Fig. 2c). It might be speculated that sheep grazing and especially the accumulation of dung in this paddock had created a pattern in the soil that counteracted the pattern that would be established around the tree in the absence of significant camping. The accumulation of phosphorus-rich dung in the vicinity of the trees in the stocked paddock probably also explains the significantly larger concentration of extractable phosphorus that was consistently found in the soils in this paddock (Fig. 2c).

It is often suggested that the accumulation of nutrients around trees in grazing country is primarily the result of animal camping and that this process is detrimental because organic matter and nutrients are being redistributed from the productive pasture to the 'less valuable' zone around the tree. However, it should be

Figure 2(b). Soil properties (pH (CaCl2) and carbon) determined at Newholme plotted against log distance from trees.

noted that the redistribution of nutrients that undoubtedly takes place under the influence of grazing animals will probably occur at specific locations in grazed paddocks across the landscape whether or not trees are present (Hilder 1964; Comino 1983; Taylor *et al.* 1984; McCaskill & Cayley 2000). The results presented here suggest that a pattern is imposed on soil properties by scattered paddock trees and that this pattern is merely augmented and modified by camping activity. From the data presented, it is not possible to determine whether the trees are actively 'improving' soil properties. However, it appears that, at the very least, scattered trees under both stocked and destocked conditions 'conserve' better soil conditions within their area of influence. It might reasonably be speculated, therefore, that trees in both stocked and destocked systems have a value from a soil conservation perspective.

Conclusions

This study was small and was not extensively replicated but, nevertheless, provided some significant and interesting results with respect to the in situ effects of scattered paddock trees on surface soil properties. Very clear patterns were imposed by trees on surface soil conditions. Soils under trees had lower bulk density but higher pH, carbon, nitrogen and extractable phosphorus contents, all of which changed systematically with distance from the tree. These patterns existed for all tree species whether or not animal camping was evident.

Stocking and camping in the paddocks had, however, modified some surface soil properties. For example, surface soils of the stocked paddock were generally more acid and compact and were lower in carbon than the destocked equivalent. Extractable soil phosphorus content was considerably higher in the stocked paddock, especially where camping activity was high. However, the value of this

[c]

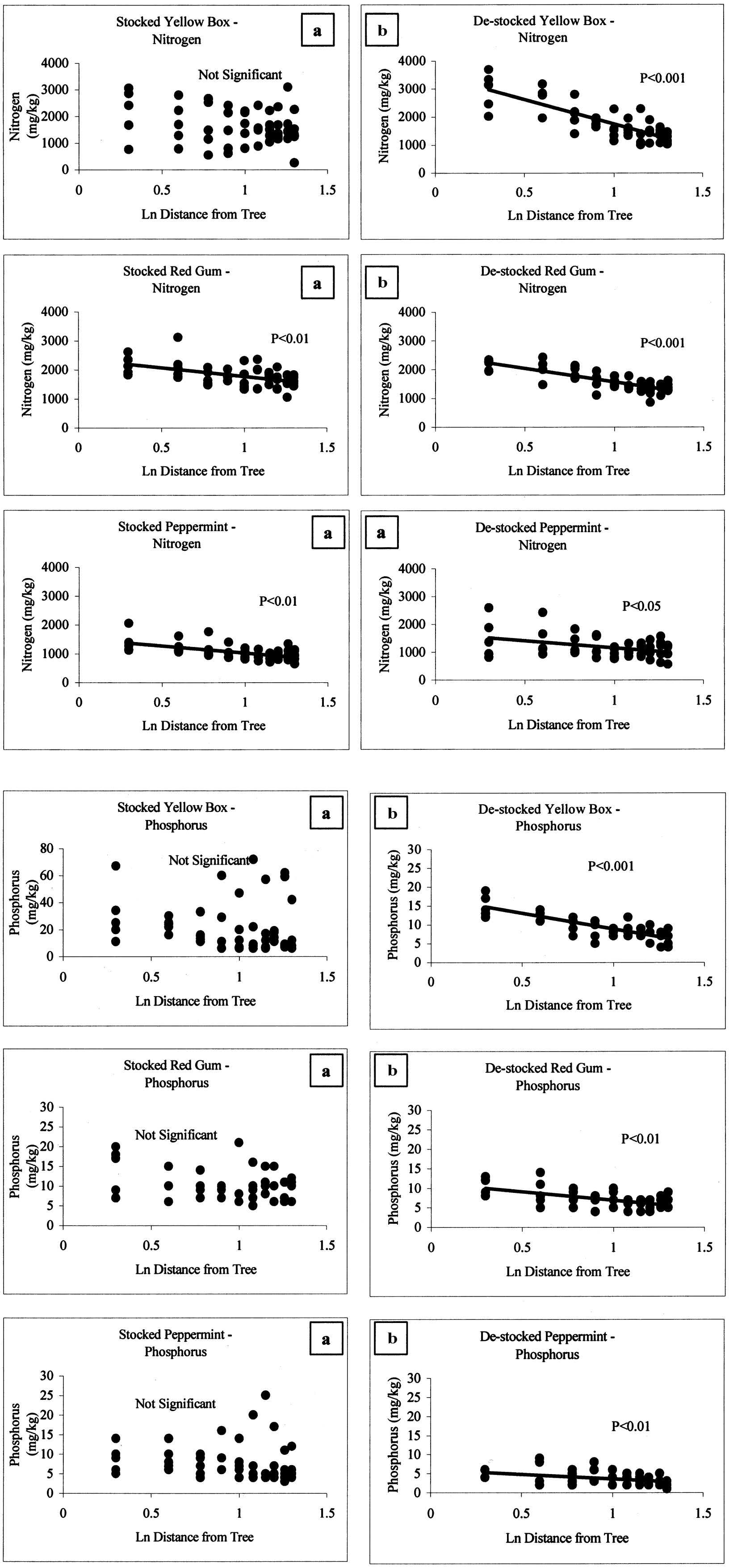


Figure 2[c]. Soil properties (nitrogen and phosphorus) determined at Newholme plotted against log distance from trees.

nutrient enrichment is probably limited given the other associated effects of stock on the soil. For some soil properties, such as nitrogen and phosphorus, sheep camping had also augmented or modified the pattern of soil properties under the trees and had, to an extent, counteracted the pattern in the soils that was found in the absence of camping.

Considering the differences that were found in the various soil properties, it might be concluded that the effects of trees on soils were beneficial and that, in this type of grazing system, in the Northern Tablelands of NSW, scattered paddock trees have value from a soil conservation perspective.

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References

Beniamino F., Ponge J. F. and Arpin P. (1991) Soil acidification under the crown of Oak trees. I. Spatial distribution. *Forest Ecology and Management* **40**, 221–232.

Bird P. R., Bicknell D., Bulman P., Burke S. J., Leys J. and Parker J. (1992) The role of shelter in Australia for protecting soils, plants and livestock. *Agroforestry Systems* **20**, 59–86.

Bochet E., Rubio J. L. and Poesen J. (1999) Modified topsoil islands within patchy Mediterranean vegetation in S E Spain. *Catena* **38**, 23–44.

Boettcher S. E. and Kalisz P. J. (1990) Single-tree influence on soil properties in the mountains of eastern Kentucky. *Ecology* **71**, 1365–1372.

Burrows D. M. and Burrows W. H. (1992) Seed production and litter fall in some eucalypt communities in central Queensland. *Australian Journal of Botany* **40**, 389–403.

Comino G. C. (1983) The role of nutrient gradients in the vegetation zonation around sheep camps on the Northern Tablelands of New South Wales. MSc Thesis, University of New England, Armidale, NSW.

Conyers M. K., Helyar K. R. and Poile G. J. (2000) pH buffering: the chemical response of acid soils to added alkali. *Soil Science* **165** (7), 560–566.

Conyers M. K., Uren N. C. and Helyar K. R. (1995) Causes of changes in pH in acidic mineral soils. *Soil Biology and Biochemistry* **27** (11), 1383–1392.

Crampton C. B. (1982) Podzolization of soils under individual tree canopies in south western British Columbia, Canada. *Geoderma* **28**, 57–61.

Duijsings J. J. H. M., Verstraten J. M. and Bouten W. (1986) Spatial variability in nutrient deposition under Oak/Beech canopy. *Zeitschrift Pflanzenernahr Bodenkunde* **149**, 718–727.

Ford E. D. and Deans J. D. (1978) The effects of canopy structure on stemflow, throughfall and interception loss in a young Sitka Spruce stand. *Journal of Applied Ecology* **15**, 905–917.

Gersper P. L. (1970) Effect of American Beech trees on the Gamma Radioactivity of soils. *Soil Science Society of America Proceedings* **34**, 318–323.

Gersper P. L. and Hollowaychuk N. (1970a) Effects of stemflow water on a Miami soil under a Beech tree I. Morphological and physical properties. *Soil Science Society of America Proceedings* **34**, 779–786.

Gersper P. L. and Hollowaychuk N. (1970b) Effects of stemflow water on a Miami soil under a Beech tree II. Chemical properties. *Soil Science Society of America Proceedings* **34**, 787–794.

Gersper P. L. and Hollowaychuk N. (1971) Some effects of stem flow from forest canopy trees on chemical properties of soils. *Ecology* **52**, 691–702.

Gregory N. G. (1995) The role of shelterbelts in protecting livestock: a review. *New Zealand Journal of Agricultural Research* **38**, 423–450.

Harrison A. F., Miles J. and Howard D. M. (1988) Phosphorus uptake by birch from various depths in the soil. *Forestry* **61** (4), 349–358.

Helyar K. R. and Porter W. M. (1989) Soil acidification, its measurement and the processes involved. In: *Soil Acidity and Plant Growth* (ed. A. D. Robson) pp. 61–101. Academic Press, Sydney.

Hilder E. J. (1964) The distribution of plant nutrients by sheep at pasture. *Proceedings of the Australian Society of Animal Production* **5**, 241–248.

Isbell R. F. (1996) *The Australian Soil Classification*. CSIRO Publishing, Melbourne.

Kitching R. L. and Allsop P. G. (1997) *Prionocyphon niger* Sp. N. (Coleoptera: Scirtidae) from water-filled tree holes in Australia. *Journal of the Australian Entomological Society* **26**, 73–79.

Law B. S., Chidel M. and Turner G. (2000) The use by wildlife of paddock trees on farmland. *Pacific Conservation Biology* **6** (2), 130–143.

Leys J. F. and McTainsh G. H. (1999) Dust and nutrient deposition to riverine environments of south-eastern Australia. *Zeitschrift für Geomorphologie* **116**, 59–76.

McCaskill M. R. and Cayley J. W. D. (2000) Soil audit of a long-term phosphate experiment in south-western Victoria: total phosphorus, sulfur, nitrogen and major cations. *Australian Journal of Agricultural Research* **51**, 737–748.

Majer J. and Recher H. (2000) A tree alone. *Nature Australia* Winter 2000, 58–65.

Nilsson I. S., Miller H. G. and Miller J. D. (1982) Forest growth as a possible cause of soil and water acidification: an examination of concepts. *Oikos* **39**, 40–49.

Noble A. D., Zenneck I. and Randall P. J. (1996) Leaf litter alkalinity and neutralisation of soil acidity. *Plant and Soil* **179**, 293–303.

Ozolins A., Brack C. and Freudenberger D. (2001) Abundance and decline of isolated trees in the agricultural landscapes of central New South Wales. *Pacific Conservation Biology* **7**, 195–203.

Reid N., Boulton A., Nott R. and Chilcott C. (1997) Ecological sustainability of grazed landscapes on the Northern Tablelands of New South Wales (Australia). In: *Frontiers in Ecology: Building the Links* (eds N. Klomp and I. Lunt). Elsevier, Oxford.

Reid N. and Thompson D. (1999) Economics of windbreaks and sheep production on the northern Tablelands. In: *Sustainable and Practical Vegetation Management Into the New Millennium – Economics and Environment* (ed. Norsearch Limited). Conference Proceedings of the Australian Association of Natural Resource Management; 28–30 June 1999, Coffs Harbour. Norsearch Limited, Lismore, NSW.

Ryan P. J. and McGarity J. W. (1983) The nature and spatial variability of soil properties adjacent to large forest Eucalypts. *Journal of the Soil Science Society of America* **47**, 286–293.

Sinclair R. (1983) The impact of trees on the physical environment. In: *Trees in the Rural Environment: Towards a Greenprint for S Australia.* (eds F.J. van der Sommen, R. Boardman and V. Squires). 18–20 March, Roseworthy Agricultural College. Roseworthy Agricultural College, Roseworthy, South Australia.

Skeffington R. A. (1984) Effects of acid deposition and natural soil acidification processes on soil: Some studies in the Tillingbourne catchment, Leith Hill, Surrey. *SEESOIL Occasional Paper* **2**, 18–36.

Stace H. C. T., Hubble G. D., Brewer R. *et al.* (1968). *A Handbook of Australian Soils.* Rellim Technical Publications, Glenside, SA.

Taylor J. A. and Hedges D. A. (1984) Some characteristics of the trees used by sheep for diurnal camping and differences between the shade and nocturnal camps in a paddock on the Northern Tablelands of NSW. *Australian Rangeland Journal* **6**, 3–9.

Taylor J. A., Hedges D. A. and Whalley R. D. B. (1984) The occurrence and distribution and characteristics of sheep camps on the Northern Tablelands of NSW. *Australian Rangeland Journal* **6**, 10–16.

Tommerup I. C. and Bougher N. L. (2000) The role of ectomycorrhizal fungi in nutrient cycling in temperate Australian woodland. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs and C. J. Yates) pp. 190–224. Surrey, Beatty and Sons, Chipping Norton, NSW.

Walpole S. (1999) Assessment of the economic and ecological impacts of remnant vegetation on pasture productivity. *Pacific Conservation Biology* **5**, 28–35.

Yan F., Schubert S. and Mengel K. (1996) Soil pH increase due to biological decarboxylation of organic ions. *Soil Biology and Biochemistry* **28**, 617–624.

Zhang L., Dawes W. R., Hatton T. J., Reece P. H., Beale G. T. H. and Packer I. (1999) Estimation of soil moisture and groundwater recharge using the TOPOG_IRM model. *Water Resources Research* **35** (1), 149–161.

Zinke P. J. (1962) The pattern and influence of individual forest trees on soil properties. *Ecology* **43** (1), 130–133.