SOIL PROPERTIES UNDER PINE FOREST AND PASTURE AT TWO HILL COUNTRY SITES IN CANTERBURY

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ABSTRACT

Soil chemical properties under grassland were compared with those under adjoining first-rotation pine forest aged 20 and 25 years, at coastal and inland hill country sites in Canterbury, New Zealand. The pasture sites had been treated with fertiliser but not limed. Organic carbon, total nitrogen, sulphur, and phosphorus, and exchangeable potassium, calcium, and magnesium levels were lower in soil beneath forest at one or both of the sites. In contrast, available phosphorus and sulphur concentrations were marginally higher beneath forest at both sites despite fertiliser application to grassland. Mineralisable nitrogen also was higher beneath forest at the inland site, but not at the more agriculturally developed coastal site. Differences between sites for total sulphur and exchangeable magnesium were ascribed to greater atmospheric inputs of these elements to forest at the coastal site. At both sites, soils under forest were more acid and had higher exchangeable aluminium levels. Differences between forest and grassland for organic carbon and total nitrogen and phosphorus were confined to the upper soil layers (0–0.1 m), while differences in soil acidity progressed to a depth of 0.2 m, and differences in exchangeable cations were evident to 0.4 m, the greatest depth measured. Soil (< 2 mm) bulk density and nutrient pools were measured at the coastal site, and bulk density was similar beneath forest and grassland. Total nitrogen and exchangeable potassium and magnesium pools to 0.3 m depth were lower under forest than grassland, while the exchangeable aluminium pool was higher under forest. Organic carbon, total phosphorus and sulphur, and exchangeable calcium pools were similar under the two types of vegetation. Lower concentrations and pools of nutrients in soil beneath forest may have been due to uptake and sequestration of nutrients in forest biomass, or to fertiliser application to grassland, although the latter would have been counteracted to some extent by nutrient removals by grazing animals.

Keywords: acidity; aluminium; carbon; nutrients; pasture; pine; soil.

INTRODUCTION

Increasing areas of New Zealand hill country grasslands are being converted from pasture to exotic forest plantations. An understanding of the impact of grassland afforestation on soil properties is important for determining the long-term sustainability of forestry as a land use, and is needed to fulfil requirements of the Resource Management Act, which requires a knowledge of likely effects of land-use activities on the environment

(N.Z.Government 1994). Information on the influence of afforestation on soil carbon (C) storage may also be required for carbon budgeting purposes as New Zealand has adopted a policy whereby carbon storage by exotic plantation forests may be used to offset increases from other sources to meet its commitments under the Framework Convention for Climate Change (MfE 1997).

Afforestation of grassland has been shown to influence a number of soil chemical properties. Available nitrogen (N), phosphorus (P), and sulphur (S) levels are commonly higher under conifers than grass (Fisher & Stone 1969; Davis & Lang 1991; Hawke & O'Connor 1993; Davis 1994; Belton *et al.* 1995; Condron *et al.* 1996), the increase being ascribed to enhanced mineralisation of soil organic matter under conifers (Fisher & Stone 1969; Davis & Lang 1993; Davis 1995). The effect of afforestation on total nitrogen and phosphorus and exchangeable cation levels is not as consistent. These may be lower under younger conifer stands because of uptake and sequestration of nutrients in forest biomass (Giddens *et al.* 1997; Davis 1998; Alfredsson *et al.* 1998; Perrot *et al.* 1999). However, they may be higher under older conifer stands than under grass (Belton *et al.* 1995; Davis 1998). Recent studies indicate that distance from the sea coast may influence the way in which soil properties are changed by afforestation. Giddens *et al.* (1997) and Parfitt *et al.* (1997) observed elevated exchangeable sodium (Na) and magnesium (Mg) levels in soils beneath forest, and this they attributed to interception of airborne sea salts by the forest canopy. Increases in topsoil acidity have been commonly observed under forested sites (Davis 1998; Hawke & O'Connor 1993; Giddens *et al.* 1997; Parfitt *et al.* 1997), which may lead to elevated exchangeable aluminium (Al) levels (Davis & Lang 1991).

Most of the research undertaken on the influence of afforestation on soil properties in New Zealand has used paired adjoining grassland and ex-grassland forest sites, chosen to be as similar as possible, to make comparisons of soil properties. Paired-site studies have drawbacks in that the treatments lack replication, and important factors such as soil variation, fertiliser application, and grazing may not be fully controlled. Further, in addition to the influence of stand age and distance from the ocean already described, climatic and soil factors are likely to influence the impact of afforestation on soil properties. Consequently, studies at different sites are required to determine whether general conclusions are to be reached about the influence of afforestation on soil properties. The study reported here, in which soil under forest was compared with grassland at coastal and inland hill country sites in Canterbury, was undertaken to contribute to the data on the influence of afforestation on soil properties.

METHODS

Study Sites

The study sites were located at Teviotdale (lat.43°07′S, long.172°48′E) and Okuku (lat.43°06′S, long.172°27′E), 3 and 27 km respectively from the east coast of Canterbury, in the central South Island of New Zealand. The forest at Teviotdale (part of Omihi Forest) was planted with *Pinus radiata* D. Don on land which had been cultivated and sown in pasture species some 50 years previously, and which had since become infested with the inedible nasella tussock (*Nasella trichomata* (Nees) Arechav.). The forest at Okuku was planted with *P. muricata* D. Don in silver tussock (*Poa cita* Edgar) grassland, which had not been cultivated or treated with fertiliser, as part of an agroforestry venture. Originally both sites would have been covered by native forest (podocarp/hardwood forest at Teviotdale and beech forest at Okuku), which would have been removed by burning, probably in pre-European times (Molloy 1969). Sheep grazed the grassland at both sites, and sheep had access to the forest at Okuku, but not at Teviotdale. Site characteristics are given in Table 1. The soil at Okuku was a stony silt loam derived from colluvium; that from Teviotdale was a silt loam derived from loess. The standing timber volume at Teviotdale substantially exceeded that of the younger, higher elevation, Okuku Forest. The Teviotdale site had been planted at 750 stems/ha and thinned at age 10 and pruned to 6 m height. Initial stocking and management history were not available for the Okuku site. No fertiliser had been applied to either forest after planting. Superphosphate fertiliser (9% P, 12% S, 20% Ca) at approximately 125 kg/ha had been applied infrequently to the grassland at Teviotdale. One treatment of 600 kg superphosphate/ha was applied to the grassland at Okuku, soon after the forest was planted.

TABLE 1–Site characteristics.

	Teviotdale	Okuku
Distance from ocean (km)	3	27
Grassland vegetation	Ryegrass, clover, sweet vernal, plantain	Silver tussock, browntop, clover
Altitude (m)	170	620
Rainfall (mm)	800	1200+
Soil series	Stonyhurst	Hurunui
Soil classification	Yellow-grey earth	Lowland yellow-brown earth
Parent material	Loess/calcareous sandstone	Greywacke colluvium
Stand age (years)	25	20
Tree stocking (stems/ha)	270	330
Tree height (m)	26.3	18.2
Stand volume (m^3/ha)	430	250

Soil Sampling

At each site, adjoining areas under pine and permanent pasture with similar soils, aspect, and slope were selected for sampling. Soil samples were collected from five locations at 20-m intervals along transects running parallel to and 20 m from the forest margin. At each location, three 65-mm-diameter cores were collected and bulked by depth. Within the forest the three sub-samples were located at a distance of 0.5, 1.0, and 1.5 m from the base of, and level with, the tree nearest the transect sample point. Within the grassland they were located within a distance of 0.5 m from transect sample point. Soils were cored to a depth of 30 cm (Teviotdale) or 40 cm (Okuku) and, after extraction, cores were cut into four or five depths (0–5, 5–10, 10–20, 20–30, and 30–40 cm).

Chemical Analysis

Soils were air dried and passed through a 2-mm sieve for determination of measures of "plant available" nutrients (mineralisable-nitrogen, Bray 2-phosphorus, sulphate-sulphur, and exchangeable cations), pH, and aluminium, and sub-samples were ground to pass a 0.25-mm sieve for determination of organic carbon, and total nitrogen, phosphorus, and sulphur. Soils were analysed for pH in water (soil:water = 1:2.5). Total nitrogen was determined in hydrogen peroxide - sulphuric acid digests. Nitrogen was determined in the digests colorimetrically (Searle 1975). Total sulphur was determined in nitric-perchloric acid digests by a turbidimetric barium sulphate procedure. Total, inorganic, and organic phosphorus were determined by the method of Walker & Adams (1958). Inorganic and total phosphorus were extracted in normal sulphuric acid before and after ignition (at 550°C for 1 hour) respectively, and the phosphorus content of the extracts was determined by the vanadomolybdate method. Organic phosphorus was determined by difference. Organic carbon was determined by the Walkley & Black method as described by Nicholson (1984). Mineralisable-nitrogen was determined by aerobic incubation of samples in plastic bags (wall thickness = 30 μm) at ≅ 25°C for 6 weeks and extraction of samples in 2N potassium chloride. Before incubation, soil moisture contents were adjusted so that forest and grassland samples of similar depth had similar moisture content. Moisture contents were maintained by periodic weighing of incubating samples, and addition of water as required. Ammonium and nitrate in the extracts were determined by the method of Bremner (1965). Sulphate-sulphur was determined by ion chromatography in 20 mM phosphate extracts of soil. Bray 2-phosphorus was determined in ammonium fluoride/ hydrochloric acid extracts as described by Nicholson (1984). Exchangeable potassium (K), calcium (Ca), and magnesium were also determined in these extracts (Nicholson 1984). Exchangeable aluminium was determined in M potassium chloride as described by Percival *et al.* (1996), except that the extracts were filtered through Whatman No.42 filter paper, not centrifuged. Cations were determined in extracts by atomic adsorption spectroscopy.

The bulk density of < 2-mm soil was determined on all depths of the Teviotdale soil and applied to nutrient concentration data to determine total nutrient mass in the samples. The soil at Okuku was too stony to derive accurate bulk density data from the cores obtained.

RESULTS AND DISCUSSION

Bulk Density

The bulk density of < 2-mm soil was similar under forest and grassland at Teviotdale (Table 2). Other New Zealand studies have similarly shown no difference in bulk density between grassland and adjoining first-rotation forest (Parfitt *et al.* 1997; Giddens *et al.* 1997; Davis 1994; Ross *et al.* 1999; Chen *et al.* 2000).

Soil Acidity

Soil pH was lower under forest than grassland at both sites (Table 2). This is consistent with previous forest-grassland comparisons in New Zealand (Davis & Lang 1991; Davis 1994; Hawke & O'Connor 1993; Giddens *et al.* 1997; Parfitt *et al.* 1997). In Canada Fuller & Anderson (1993) observed lower pH beneath aspen forest than beneath adjoining prairie in strongly leached soils, but no difference where leaching was less intense. In the present study the difference in pH was apparent only in the upper soil layers (0–0.2 m) (Fig. 1). Hawke & O'Connor (1993) and Alfredsson *et al.* (1998) reported pH reductions with afforestation to a depth of 0.3 m (the greatest depth measured), although the pH decline under forest generally decreased with increasing depth. The greater acidification in surface layers

TABLE 2–Mean total and available soil nutrient and aluminium concentrations and pH in mineral soil under grassland and forest at two sites, with main effect and interaction probabilities from analysis of variance. Measurements are to 0.3 m at Teviotdale and 0.4 m depth at Okuku.

	Teviotdale					Okuku				
	Mean		Probability from anova			Mean		Probability from anova		
	Grassland	Forest	Vegetation	Depth	V × D	Grassland	Forest	Vegetation	Depth	V × D
Total										
Organic C (%)	3.10	2.97	0.51	<0.01	0.33	2.54	2.26	0.02	<0.01	0.22
Total N (%)	0.30	0.23	<0.01	<0.01	<0.01	0.22	0.20	0.05	<0.01	0.17
Total S (ppm)	255	247	0.50	0.49	0.52	255	228	0.02	0.04	0.56
Total P (ppm)	605	546	<0.01	<0.01	<0.01	422	430	0.72	<0.01	0.55
Organic P (ppm)	471	407	<0.01	<0.01	<0.01	290	278	0.50	<0.01	0.22
Inorganic P (ppm)	134	139	0.40	<0.01	0.29	132	152	0.07	0.37	0.17
Available										
Min.-N* (ppm)	113	76	<0.01	<0.01	<0.01	84	96	0.02	<0.01	0.72
Bray 2-P (ppm)	8.9	10.4	0.08	<0.01	0.80	4.1	6.5	<0.01	<0.01	0.60
Sulphate-S (ppm)	2.4	3.3	<0.01	<0.01	0.07	2.6	3.9	<0.01	0.01	0.77
Exch.-K (mol/kg)	0.67	0.33	<0.01	<0.01	0.04	0.53	0.30	<0.01	<0.01	0.74
Exch.-Ca (cmol/kg)	6.4	5.7	<0.01	<0.01	0.01	2.8	2.1	<0.01	<0.01	0.66
Exch.-Mg (cmol/kg)	1.9	1.7	<0.01	<0.01	<0.01	1.7	1.3	<0.01	<0.01	0.32
Exch.-Al (cmol/kg)	0.19	0.72	<0.01	0.14	0.67	3.3	3.8	0.03	<0.01	0.05
pH	5.4	5.2	0.01	0.15	0.30	5.1	5.0	<0.01	<0.01	0.11
Bulk density (g/cm^3)	1.18	1.24	0.17	<0.01	0.28	–	–	–	–	–

* Min.-N = mineralisable nitrogen

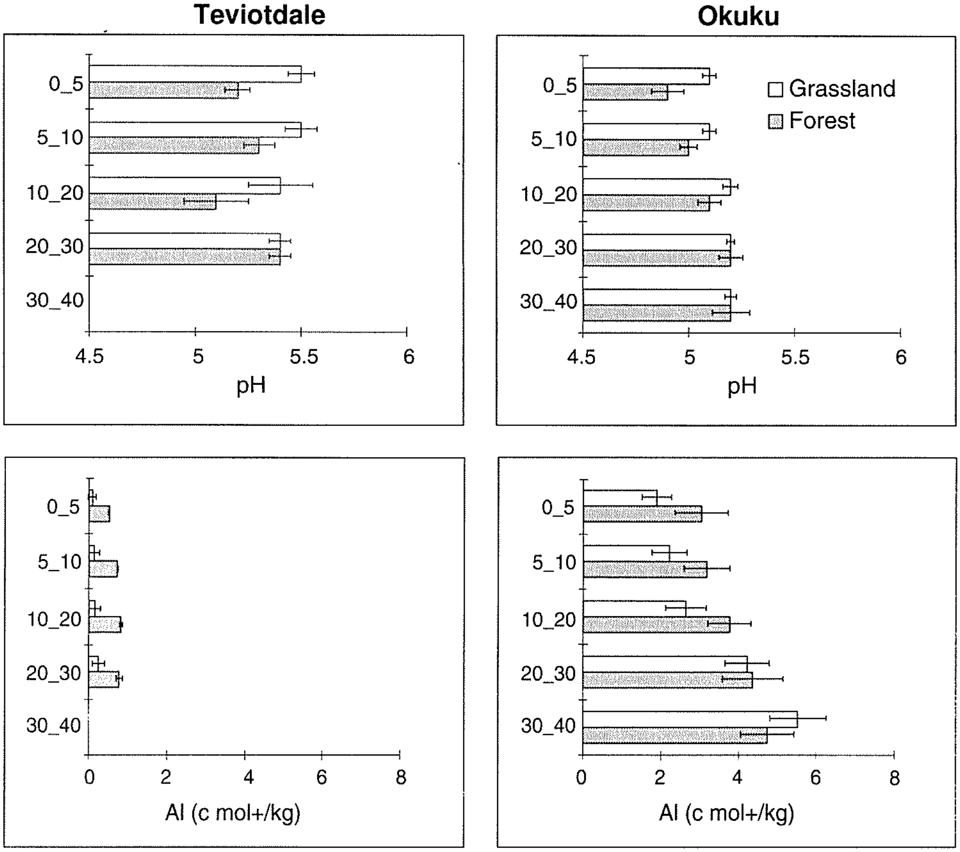

FIG. 1–Soil pH exchangeable aluminium concentrations in soil beneath adjoining grassland and forest at coastal (Teviotdale) and inland (Okuku) hill country sites in Canterbury. Vertical axis shows soil depth (cm). Bars show standard errors.

may be due to organic acids from needle litter (Gahni *et al.* 1994). Alternatively, the reduction in pH under forest may be more pronounced in topsoils because of greater cation uptake and consequent proton release. In the present study, however, cation depletion under forest at depths below 0.2 m (0.28–0.40 $cmol^+/kg$) was similar to that in the 0–0.1 m layers (0.26–0.43 $cmol^+/kg$).

At low pH the weathering of minerals is accelerated, resulting in enhanced release of aluminium, which may become adsorbed on to soil exchange sites. This is exemplified in the present study where exchangeable aluminium values were higher in forest than in grassland soil at both sites (Table 2). At Okuku the difference was apparent only in the upper 0.2 m, consistent with the decline in pH; however, at Teviotdale the difference was apparent at all measured depths (Fig. 1), indicating that the increase in exchangeable aluminium preceded the decline in pH. The increase in exchangeable aluminium with afforestation is consistent with previous studies by Davis & Lang (1991) and Alfredsson *et al.* (1998) who reported higher exchangeable aluminium levels in soils under conifers than under adjoining unimproved grassland at several South Island sites. In contrast, Giddens *et al.* (1997) reported no significant difference in mean exchangeable aluminium levels between several forest and improved grassland sites in the North Island, although levels appeared elevated under forest at some sites. In acid soils aluminium toxicity is generally considered to be a major growth-limiting factor for sensitive species. In terms of critical soil threshold values for pasture plants, Edmeades *et al.* (1983) found that white clover was affected (50% reduction in yield) by aluminium toxicity associated with more than 1–2 cmol(+)/kg aluminium extracted in potassium chloride. Aluminium toxicity should therefore not have been a problem at Teviotdale, but at Okuku aluminium levels in grassland were on the borderline for toxicity, and afforestation may have pushed levels above the toxicity threshold for species such as white clover. If forest land at Okuku were to be returned to pasture, liming might be needed to increase the soil pH and reduce aluminium levels to obtain maximum pasture yields. However, potassium chloride-extractable aluminium values may provide a misleading indication of potential aluminium toxicity status in some soils (Percival *et al.* 1996), and so further investigation would be required to determine if liming was necessary to obtain optimum pasture yields.

Organic Carbon

Organic carbon concentrations were significantly lower under forest than grassland at Okuku, but not at Teviotdale (Table 2). Lower organic carbon concentrations under conifers than under grasslands have been reported from New Zealand studies involving comparisons with both unimproved grasslands (Davis & Lang 1991; Alfredsson *et al.* 1998) and developed pastures (Parfitt *et al.* 1997; Alfredsson *et al.* 1998; Ross *et al.* 1999; Perrot *et al.* 1999). However, other studies have shown no difference between grassland and forest (Davis 1994; Giddens *et al.* 1997), and Davis & Lang (1991) noted higher concentrations under older pine stands (30 to 50 years) on dry outwash gravel soils than under adjoining unimproved grassland. Fuller & Anderson (1993) observed substantially lower organic carbon concentrations beneath Canadian aspen forest than beneath adjoining prairie in strongly leached soils, but reduced difference where leaching was less intense. Corre *et al.* (1999) found no difference between forest and grassland in mean soil carbon concentrations in the north-eastern United States.

The organic carbon pool in the 0–0.1 m layer was lower under forest at Teviotdale by 3.4 t/ha, but the difference was not significant (Table 3). When the 0–0.3 m layer is considered the organic carbon pool was slightly higher under forest. These results are in accord with those of Giddens *et al.* (1997), Chen *et al.* (2000), and Davis (1994) who reported no difference in soil carbon pools between pasture and pine (in the comparison of Davis the pine stand was only 10 years old). However, Parfitt *et al.* (1997) and Ross *et al.* (1999) reported substantially lower organic carbon pools beneath forest approximately 20 years old than beneath adjoining unplanted grassland (19.7 and 30 t/ha respectively to a depth of 0.2 m). Scott *et al.* (1999) also found soil carbon to be lower under pines than adjoining pasture, the difference being significant for three sites on volcanic soils, but not for one site on a soil with high clay activity. These authors suggested the differences between soils in their response to afforestation might result from differences in clay mineralogy, as 2:1 clay minerals such as mica and vermiculite, present in large quantities in high clay activity soils, may stabilise organic matter and protect it from losses associated with land-use change.

TABLE 3–Mass of carbon, nutrients, and aluminium (kg/ha) in mineral soil to 0.1 and 0.3 m depths beneath forest and grassland at Teviotdale, with *t*-test probabilities.

	0–0.1 m			0–0.3 m		
	Grassland	Forest	p from *t*-test	Grassland	Forest	p from *t*-test
Organic C	43465	40070	0.16	94826	97558	0.70
Total N	3959	2943	<0.01	9382	8045	0.01
Total S	259	262	0.91	955	933	0.75
Total P	728	611	<0.01	2059	2011	0.63
Min.-N *	172	103	<0.01	322	257	0.02
Sulphate-S	3.4	3.8	0.31	7	12	<0.01
Bray 2-P	11	13	0.26	29	36	0.11
Exch.-K	285	181	0.02	951	412	<0.01
Exch.-Ca	1466	1257	0.12	4464	4342	0.78
Exch.-Mg	259	259	0.99	851	752	0.07
Exch.-Al	10	60	<0.01	59	251	<0.01

* Min.-N = mineralisable nitrogen

Total Nitrogen, Phosphorus, and Sulphur

Total nitrogen concentrations were lower in soil under forest than grassland at both locations, whereas total sulphur was lower under forest at Okuku only, and total phosphorus was lower under forest at Teviotdale (Table 2). Concentrations of total nitrogen, sulphur, and phosphorus were never higher under forest. Differences in nitrogen and phosphorus concentrations were restricted to the 0–10 cm layers, but differences in sulphur concentration occurred at lower depths (Fig. 2). For sulphur the difference between sites may be associated with distance of the sites from the ocean. Because of their greater foliage area, forests are more efficient than pastures at capturing atmospheric sea-salt-derived ions such as sulphate and magnesium (Parfitt *et al.* 1999). The proximity of the Teviotdale site to the coast would have resulted in greater inputs of these ions than at Okuku, and consequently reduced differences between forest and pasture soil sulphur concentrations. The pools of total nitrogen and phosphorus were lower beneath forest than grassland in the 0–0.1 m layer at Teviotdale, whereas the total sulphur pool was similar (Table 3). Differences between the two vegetation types amounted to 1016 and 117 kg/ha for nitrogen and phosphorus respectively. In the 0–0.3 m layer only total nitrogen was significantly lower (by 1337 kg/ha) under forest.

The lower concentrations of total nitrogen, phosphorus, and sulphur under forest may be attributed to uptake and sequestration of nutrients in forest biomass, and to inputs of phosphorus and sulphur (and indirectly of nitrogen from fixation by legumes) to grassland through fertiliser application. Superphosphate supplying approximately 75 kg S/ha and 56 kg P/ha was applied to the grassland at Okuku in 1980, which could account for much of the difference in sulphur and phosphorus between the two vegetation types there. However, fertiliser application would have been counteracted to some extent by nutrient removals through grazing. The amount of fertiliser applied to grassland at Teviotdale is not known.

Lower concentrations and pools of total nitrogen and phosphorus beneath forest have been reported previously for comparisons of forest with grazed pasture treated with fertiliser,

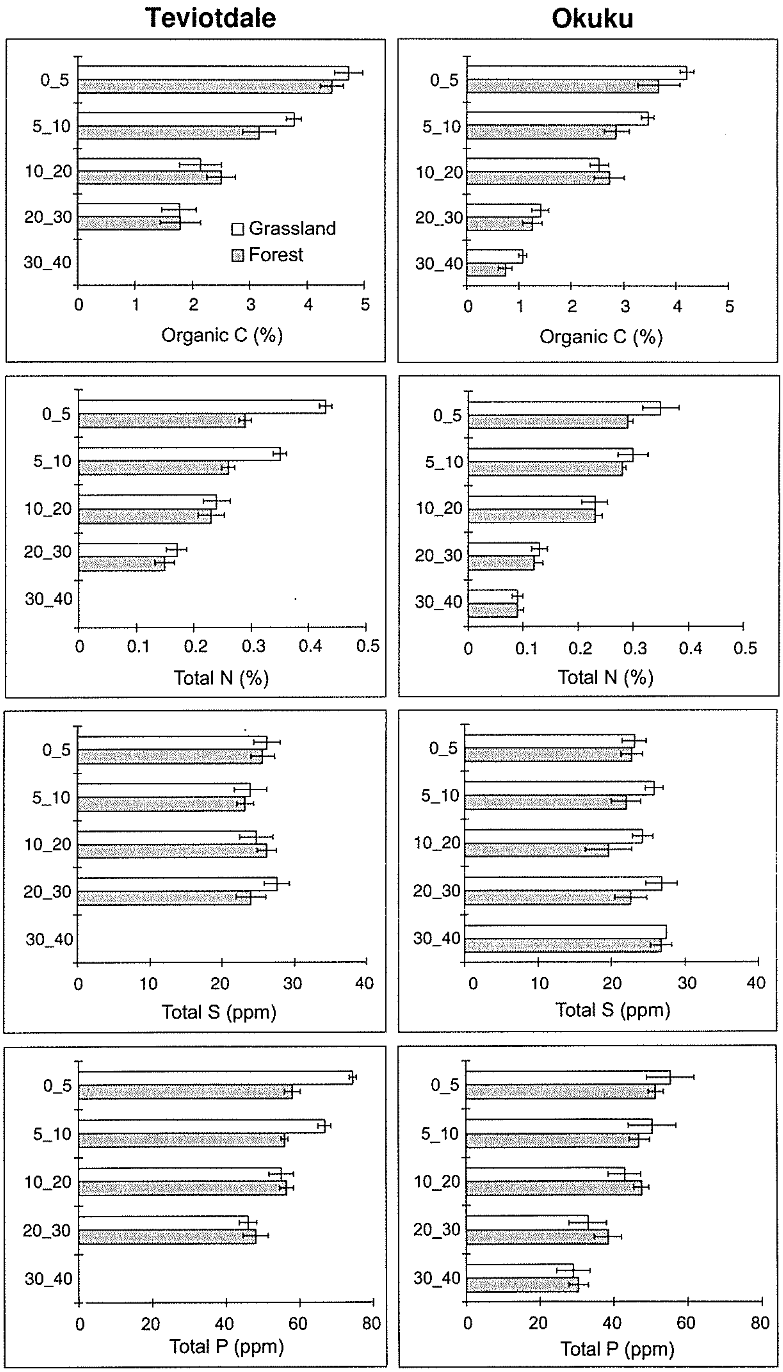

FIG. 2–Organic carbon and total nitrogen, sulphur, and phosphorus concentrations in soil beneath adjoining grassland and forest at coastal (Teviotdale) and inland (Okuku) hill-country sites in Canterbury. Vertical axis shows soil depth (cm). Bars show standard errors.

where fertiliser application and nitrogen fixation would have contributed to the difference between ecosystems (Giddens *et al.* 1997; Parfitt *et al.* 1997; Perrot *et al.* 1999; Ross *et al.* 1999). Lower concentrations of total nitrogen and phosphorus under forest have also been reported for the South Island high country region in the absence of fertiliser input to grassland, and in some cases in the absence of grazing (Davis & Lang 1991; Davis 1994; Alfredsson *et al.* 1998). Concentrations are not always lower in forest soil, however, and both total nitrogen and phosphorus have been reported as being similar or higher in topsoils under older stands (> 30 years) in the South Island high country region (Davis & Lang 1991; Belton *et al.* 1995) than under adjoining unplanted grassland. In Canada, Fuller & Anderson (1993) observed lower total nitrogen and phosphorus beneath aspen forest than beneath adjoining prairie in strongly leached soils, but no difference where leaching was less intense. Consistent with previous studies (Davis 1998; Perrot *et al.* 1999), the lower total phosphorus value under forest at Teviotdale was associated with lower organic phosphorus (Table 2). Inorganic phosphorus was similar under the two vegetation types there, whereas it was higher under forest at Okuku.

Available Nitrogen, Phosphorus, and Sulphur

In accordance with other studies (Fisher & Stone 1969; Davis & Lang 1991; Davis 1994; Hawke & O'Connor 1993; Belton *et al.* 1995; Giddens *et al.* 1997) concentrations of available nitrogen, phosphorus, and sulphur were generally higher under forest than grassland (mineralisable-nitrogen at Teviotdale was an exception, Table 2). However, the differences, though significant, were generally smaller than found in earlier comparisons. Application of superphosphate fertiliser to the grassland may have contributed to the reduced differences observed here for nitrogen, because of increased nitrogen-fixation by clover, but does not seem to have contributed to the small differences for phosphorus and sulphur as values were low in both forest and grassland systems at both sites (Table 2). At Teviotdale the pool of mineralisable-nitrogen was higher in grassland soil at both soil depths (by about 70 kg/ha), and sulphate-sulphur was higher in grassland in the 0–0.3 m layer, though the difference amounted to only 5 kg/ha (Table 3).

Nitrogen mineralisation was highest in the upper soil layers at both sites (Fig. 3). Nitrate (NO_3^-) was the dominant form (96–100%) of nitrogen produced on mineralisation of grassland in all soil layers at Teviotdale, whereas under forest nitrate declined down the profile from 74% of total nitrogen produced in the upper soil layer to 13% in the 0.2–0.3 m layer (Fig. 3). At Okuku ammonium (NH_4^+) was the dominant nitrogen form produced in both forest and grassland soil, although nitrate production in grassland soil (6–26%) still exceeded that in forest soil (3–13%). These results differ from those of Ross *et al.* (1999) who found nitrate to be the dominant anion produced in both grassland and pine soils of acidity comparable to the soils in the present study. Lower nitrate production at Okuku may be due to the higher soil aluminium levels there. In a greenhouse study, Ohno *et al.* (1988) found that soil amended with aluminium reduced nitrification rates, and Morris & Boerner (1998) found that nitification rate was strongly and positively correlated with the soil exchangeable calcium/aluminium ratios in mixed North American hardwood forest. In the present study, soil calcium/aluminium ratios were much higher at Teviotdale (range = 6.7–91.6) than at Okuku (range = 0.2–2.1).

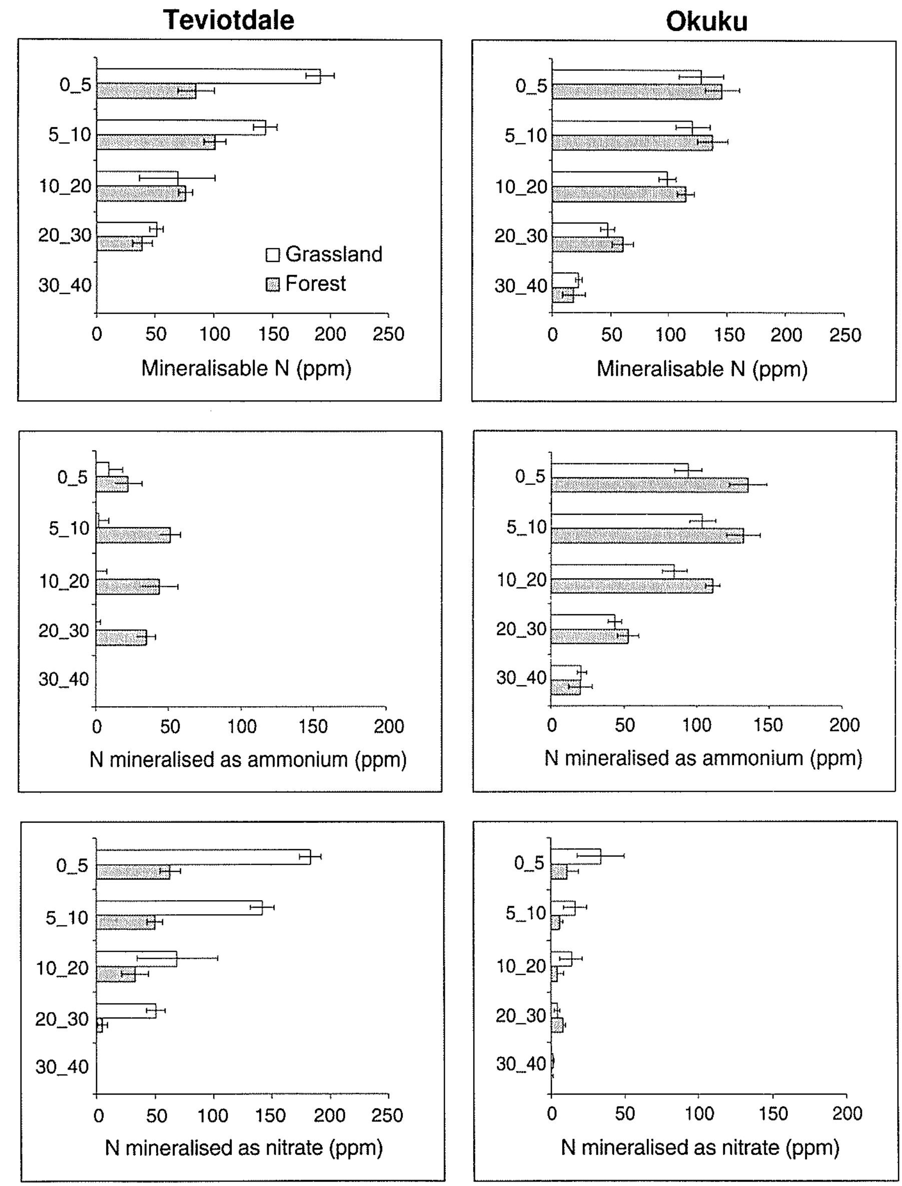

FIG. 3–Total mineralisable nitrogen and the amounts of nitrogen mineralised as ammonium and nitrate in soil beneath adjoining grassland and forest at coastal (Teviotdale) and inland (Okuku) hill country sites in Canterbury. Vertical axis shows soil depth (cm). Bars show standard errors.

Exchangeable Cations

At both sites exchangeable potassium, calcium, and magnesium concentrations were lower in most soil layers under forest than under grassland, the main exception being for magnesium in the upper layers at Teviotdale (Table 2, Fig. 4). Pools of exchangeable

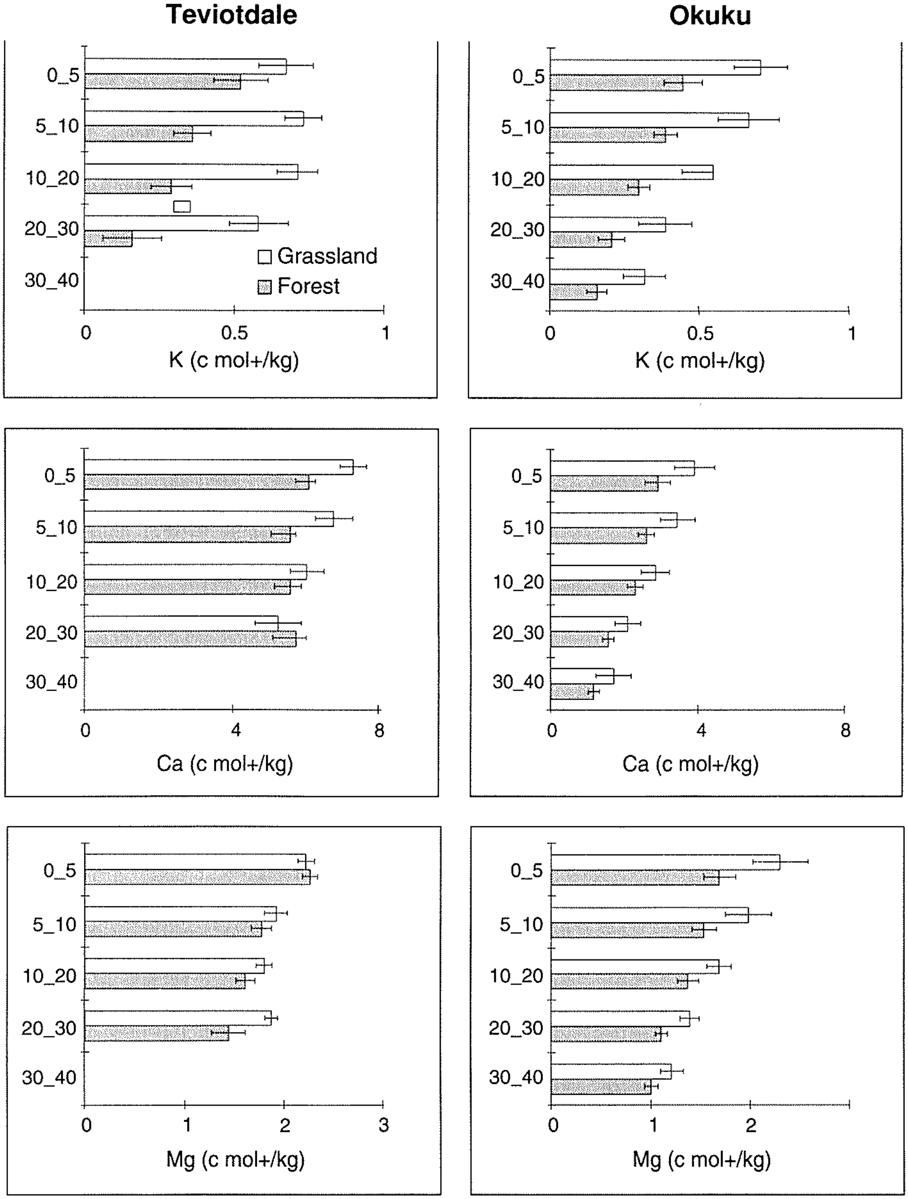

FIG. 4–Exchangeable cation concentrations in soil beneath adjoining grassland and forest at coastal (Teviotdale) and inland (Okuku) hill country sites in Canterbury. Vertical axis shows soil depth (cm). Bars show standard errors.

potassium and calcium at Teviotdale were lower in forest than grassland soil in the 0–0.1 m layer, by approximately 100 and 210 kg for potassium and calcium respectively. The exchangeable magnesium pool was similar in forest and grassland soil. At the 0–0.3 m depth, pools of all cations were lower beneath forest than grassland, but for calcium the difference was smaller than for the 0–0.1 m depth, and not statistically significant. Lower cation concentrations under young forest stands than under grassland have been reported by Davis (1998) and Alfredsson *et al.* (1998), and have been ascribed to uptake and sequestration in forest biomass. Perrot *et al.* (1999) found both concentrations and pools of exchangeable cations declined with increasing tree stocking rates in an agroforestry trial, and suggested that reduced exchange site availability associated with reduced organic matter under higher stocking rates might contribute to the lower cation concentrations. In contrast, Giddens *et al.* (1997) and Parfitt *et al.* (1997) reported elevated concentrations of exchangeable sodium and magnesium (but lower calcium) under North Island pine stands compared with adjoining grasslands. The higher levels under forest were attributed to dry deposition of sea-salt on to the forest canopies, and subsequent transfer to the soil. Sea-salt deposition may explain the lack of reduction in magnesium concentrations in the upper soil beneath forest at Teviotdale (Fig. 4).

CONCLUSIONS

Impacts of afforestation on grassland soil properties may vary depending on factors such as stand age, access of grazing animals to forest, fertiliser history, or proximity to the ocean as a source of sea-salts. In the present study the main differences between forest and grassland soils were lower concentrations and pools of nutrients, and higher acidity and exchangeable aluminium levels in soil beneath forest. The lower nutrient concentrations and pools under forest may be ascribed to uptake and sequestration of nutrients in forest biomass and to fertiliser inputs to grassland, although nutrient removals by grazing animals would have counteracted the latter to some extent. Differences in concentrations of total sulphur and magnesium between forest and grassland were greater at Okuku than at Teviotdale, possibly because of greater inputs of these elements from sea-salt at the more coastal Teviotdale site. The present results are generally consistent with previous studies which have compared soils beneath grassland and forests of a similar age to those in this study. Differences between forest and grassland in carbon, nitrogen, and phosphorus were largely restricted to the upper soil layers (0–0.1 m), while differences in acidity progressed to a depth of 0.2 m, and differences in cations (including aluminium) were seen to 0.4 m, the greatest depth measured.

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REFERENCES

ALFREDSSON, H.; CONDRON, L.M.; CLARHOLM, M.; DAVIS, M.R. 1998: Changes in soil acidity and organic matter following the establishment of conifers on former grasslands in New Zealand. *Forest Ecology and Management 112*: 245–252.

BELTON, M.C.; O'CONNOR, K.F.; ROBSON, A.B. 1995: Phosphorus levels in topsoils under conifer plantations in Canterbury high-country grassland. *New Zealand Journal of Forestry Science 25*: 265–282.

BREMNER, J.M. 1965: Inorganic forms of nitrogen. Pp. 1179–1206 *in* Black, C.A.; Evans, D.D.; White, J.L.; Ensminger, L.E.; Clark, F.E. (Ed.) "Methods of Soil Analysis". *American Society of Agronomy, Madison, Wisconsin, Agronomy Series No. 9.*

CHEN, C.R; CONDRON, L.M.; DAVIS, M.R.; SHERLOCK, R.R. 2000: Effects of afforestation on phosphorus dynamics and biological properties in a New Zealand grassland soil. *Plant and Soil 220*: 151–163.

CONDRON, L.M.; DAVIS, M.R.; NEWMAN, R.H.; CORNFORTH, I.S. 1996: Influence of conifers on the forms of phosphorus in selected New Zealand grassland soils. *Biology and Fertility of Soils 21*: 37–42.

CORRE, M.D.; SCHNABLE, R.R.; SHAFFER, J.A. 1999: Evaluation of soil organic carbon under forests, cool-season and warm-season grasses in the northeastern US. *Soil Biology and Biochemistry 31*: 1531–1539.

DAVIS, M.R. 1994: Topsoil properties under tussock grassland and adjoining pine forest in Otago, New Zealand. *New Zealand Journal of Agricultural Research 37*: 465–469.

———1995: Influence of radiata pine seedlings on chemical properties of some New Zealand montane grassland soils. *Plant and Soil 176*: 255–262.

———1998: Soil impacts of afforestation in the high country. *New Zealand Forestry 42*: 34–38.

DAVIS, M.R.; LANG, M.H. 1991: Increased nutrient availability in topsoils under conifers in the South Island high country. *New Zealand Journal of Forestry Science 21*: 165–179.

EDMEADES, D.C.; SMART, C.E.; WHEELER, D.M. 1983: Aluminium toxicity in New Zealand soils: preliminary results on the development of diagnostic criteria. *New Zealand Journal of Agricultural Research 26*: 493–501.

FISHER, R.F.; STONE, E.L. 1969: Increased availability of nitrogen and phosphorus in the root zone of conifers. *Soil Science Society of America Proceedings 33*: 955–961.

FULLER, L.G.; ANDERSON, D.W. 1993: Changes in soil properties following forest invasion of Black soils of the Aspen Parkland. *Canadian Journal of Soil Science 73*: 613–627

GHANI, A.; DEXTER, M.; PERROT, K.; O'CONNOR, M.B.; HAWKE, M.F. 1994: Role of pine needles in declining soil pH and nutrient cycling under agroforestry systems of cultivation. Proceedings of the New Zealand Society of Soil Science Conference, Lincoln University, November. 58 p.

GIDDENS, K.M.; PARFITT, R.L.; PERCIVAL, H.J. 1997: Comparison of some soil properties under *Pinus radiata* and improved pasture. *New Zealand Journal of Agricultural Research 40*: 409–416.

HAWKE, M.F.; O'CONNOR, M.B. 1993: Soil pH and nutrient levels at Tikitere agroforestry research area. *New Zealand Journal of Forestry Science 23*: 40–48.

MfE 1997: "Climate Change: The New Zealand Response ll. New Zealand's Second Communication under the Framework Convention on Climate Change". Ministry for the Environment. 191 p.

MOLLOY, B.P.J. 1969: Recent history of the vegetation. Pp. 340–360 *in* Knox, G.A. (Ed.) "The Natural History of Canterbury". A.H. and A.W.Reed, Wellington.

MORRIS, S. J.; BOERNER, R. E. J. 1998: Interactive influences of silvicultural management and soil chemistry upon soil microbial abundance and nitrogen mineralization. *Forest Ecology and Management 103(2–3)*: 129–139.

N.Z.GOVERNMENT 1994: The Resource Management Act 1991. *New Zealand Statutes 2(69)*: 595–967.

NICHOLSON, G. 1984: Methods of soil, plant, and water analysis. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.70.*

OHNO, T.; SUCKOFF, E.I.; ERICH, M.S.; BLOOM, P.R.; BUSCHENA, C.A.; DIXON, R.K. 1988: Growth and nutrient content of red spruce seedlings in soil amended with aluminium. *Journal of Environmental Quality 17*: 666–672.

PARFITT, R.L.; PERCIVAL, H.J.; DAHLGREN, R.A.; HILL, L.F. 1997: Soil and solution chemistry under pasture and radiata pine in New Zealand. *Plant and Soil 191*: 279–290.

PERCIVAL, H.J.; GIDDENS, K.M.; LEE, R.; WHITTON, J.S. 1996: Relationships between soil solution aluminium and extractable aluminium in some moderately acid New Zealand soils. *Australian Journal of Soil Research 34*: 369–379.

PERROT, K.W.; GHANI, A.; O'CONNOR, M.B.; WALLER, J.E. 1999: Tree stocking effects on soil chemical properties at the Tikitere agroforestry research area. *New Zealand Journal of Forestry Science 29*: 116–130.

ROSS, D.J.; TATE, K.R.; SCOTT, N.A.; FELTHAM, C.W. 1999: Land-use change: effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. *Soil Biology and Biochemistry 31*: 803–813.

SCOTT, N.A.; TATE, K.R.; FORD-ROBERTSON, J.; GILTRAP, D.J.; SMITH, C.T. 1999: Soil carbon storage in plantation forests and pastures: land-use change implications. *Tellus 51B*: 326–335

SEARLE, P.L 1975: Automated colorimetric determination of ammonium ions in soil extracts with "Technicon Autoanalyser II" equipment. *New Zealand Journal of Agricultural Research 18*: 183–187.

WALKER, T.W.; ADAMS, A.F.R. 1958: Studies on soil organic matter: 1. Influence of phosphorus content of parent materials on accumulations of carbon, nitrogen, sulphur, and organic phosphorus in grassland soils. *Soil Science 85*: 307–318.