INCREASED NUTRIENT AVAILABILITY IN TOPSOILS UNDER CONIFERS IN THE SOUTH ISLAND HIGH COUNTRY

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ABSTRACT

Soils collected from eight locations under exotic conifers and adjacent undeveloped grasslands in the montane zone of the eastern South Island were analysed chemically to examine the hypothesis that conifers increase the availability of nutrients, especially phosphorus, in topsoils. Olsen and Bray-2 extractable phosphorus levels were higher under the conifers than under adjacent grasslands at most sites, with the largest absolute increases occurring under older stands on dry soils of the Mackenzie Basin. Increases were smaller under stands on hygrous high-country yellow-brown earths of the Canterbury region, but these soils were characterised by large increases in mineralisable nitrogen and sulphate-sulphur. Mean total phosphorus levels were not significantly affected by the presence of conifers, but organic phosphorus levels were lower under the conifers than under the adjacent grasslands and inorganic phosphorus levels were higher. Soil pH declined under the conifers, the decline being greater in Mackenzie soils than in the Canterbury soils. The decline in pH was accompanied by an increase in exchangeable aluminium. Bray-2 extractable potassium and magnesium levels were higher under the conifers than under grassland in the Mackenzie soils, but were lower under the conifers in the Canterbury soils.

Lolium perenne L. (ryegrass) and *Trifolium repens* L. (white clover) grown in a glasshouse experiment on soils collected from under both vegetation types responded positively to the elevated mineralisable nitrogen (ryegrass) and available phosphorus (white clover) levels. Foliar analysis of native shrubs persisting under young stands at two sites in Canterbury revealed higher concentrations of nitrogen, phosphorus, potassium, iron, copper, and at one site, zinc and manganese, than in shrubs growing in the adjacent grassland. At both sites, boron concentrations were substantially lower in one shrub species.

Mineralisation of organic matter by the pines appears to be the major mechanism for nutrient enrichment of topsoils under pines in the hygrous soils of Canterbury, but a different process, possibly transfer of nutrients from deeper horizons to the soil surface via nutrient uptake and litterfall, may be more important in the dry-hygrous soils of the Mackenzie Basin.

Keywords: exotic forests; foliage analysis; high country; nutrients; soil analysis; soil fertility; tussock grasslands.

INTRODUCTION

Extensive areas of grassland occupying the montane zone on the eastern side of the South Island, New Zealand, have been induced from the original forest or shrubland vegetation by burning and grazing. These grasslands are used predominantly for pastoral farming and are now dominated by indigenous short-tussock grasses, and adventive grasses and flatweed species. Farmers have planted small woodlots of exotic trees, mainly pines, for shelter, timber, and firewood supplies. In a survey of productivity in these woodlots, Ledgard & Belton (1985) observed that phosphorus levels in topsoils (0.5 MH_2SO_4-soluble P) under plantations were substantially higher than those normally found under grassland in the region, and in the drier areas soil acidity had also increased. Subsequent analysis of the plantation soils with the Olsen phosphorus test, which allowed comparison with a wider range of grassland samples, indicated that the phosphorus levels under conifers were generally two or three times higher than under grassland (Belton *et al.* in prep.).

Other observations also suggest that trees have a possible nutrient enrichment effect on topsoils in the region. Herbaceous species often grow better beneath or near young conifer stands than away from the trees, and logged sites show better production from reinvading pasture species than adjacent unplanted grassland.

In this paper the chemical properties of conifer plantation and grassland soils in the Canterbury high country and the Mackenzie Basin are compared. In addition, samples of the high country soils were used in a glasshouse trial to test the availability of the major plant nutrients to pasture species. The foliar nutrient concentrations of indigenous shrubs growing under two young pine stands were also measured and compared to those of shrubs growing in adjacent grassland. Possible mechanisms of nutrient enrichment of topsoils under conifers are discussed.

METHODS

Experimental Sites

Soil samples were collected from beneath conifer plantations and adjacent grasslands from eight low-montane sites during spring 1989. Three sites were located on terraces (Cave Stream, Craigieburn, Lake Coleridge) and two on hillslopes (Lyndon Hill and Lake Ida) in the Canterbury region (Table 1). Precipitation at these sites varied between 1000 and 1300 mm, and all the soils are classified as hygrous high-country yellow-brown earths (N.Z. Soil Bureau 1968). A further three sites were located on flat glacial-outwash gravel surfaces in the more arid Mackenzie Basin (precipitation 530–660 mm). Two of these soils are classified as dry-hygrous high-country yellow-brown earths (Tara Hills and Benmore), and the third as a recent soil (Rhoborough Downs). None of the sites had received fertiliser.

At Cave Stream, Craigieburn, and Lyndon Hill both the plantations and the adjacent grasslands had been fenced to exclude livestock. Native shrubs (*Dracophyllum*, *Hebe*, *Cassinia*, and *Leptospermum* spp.) at these sites were actively invading the grassland, but herbaceous species still formed the dominant ground cover. Herbaceous vegetation at Cave Stream and Craigieburn was dominated by an indigenous short tussock (*Festuca novae-zelandiae*(Hack.) Ckn.) and an adventive grass, browntop (*Agrostis tenuis* Sibth.). Lyndon Hill was dominated by a tall tussock (*Chionochloa macra* Zotov) and a herb (*Celmisia*

TABLE 1–Site characteristics

Site	Soil group	Soil set	Altitude (m)	Rainfall (mm)	Conifer species	Age of conifer stand (yr)
(1) Cave Stream	Hygrous high country YBE	Craigieburn	810	1300	*Pinus ponderosa* + *Pinus nigra*	10
(2) Craigieburn		Craigieburn	840	1300	*Pinus contorta*	10
(3) Lyndon Hill		Bealey	880	1300	*Pinus sylvestris*	23
(4) Lake Ida		Cass	610	1250	*Pinus radiata* + *Pseudotsuga menziesii*	15
(5) Lake Coleridge		Craigieburn	550	1000	*Pinus radiata*	30 (logged)
(6) Tara Hills	Dry hygrous high country YBE	Mackenzie	490	530	*Pinus nigra*	31
(7) Benmore		Mackenzie	490	610	*Pinus nigra*	47
(8) Rhoborough Downs	Recent	Tasman	530	660	*Pinus nigra*	52

spectabilis Hook. f.). At the remaining sites, livestock was excluded from the plantations but not from the grasslands. *Festuca novae-zelandiae* was prominent at all except one of these sites (Rhoborough Downs). Browntop and an adventive flatweed (*Hieracium pilosella* L.) were the dominant inter-tussock species.

The plantations varied in age from 10 to 52 years (at sample date) and were *Pinus* spp., with the exception of Lake Ida where there was a mixture of *P. radiata* D. Don and *Pseudotsuga menziesii* (Mirb.) Franco. The plantation at Lake Coleridge had been logged and windrowed at age 30, 7 years before soil sampling, and a sward of pasture species dominated by white clover, sweet vernal (*Anthoxanthum odoratum* L.), and browntop had developed. All other plantations were intact at the time of sampling.

Soil Sampling and Analysis

At each site, five 10-cm-deep soil samples were collected from the two vegetation types, each sample consisting of five turfs with surface dimensions of approximately 20 × 20 cm. Grassland samples were collected along transects at a distance of 8–10 m from the edge of the younger plantations (Cave Stream, Craigieburn, and Lake Ida), and at a distance of 20–100 m from the edges of the older plantations. Forest samples were collected along transects located between tree rows. Undecomposed needle litter was removed from the surface of forest soils before collection. Soils were passed through a 9-mm sieve and mixed before sub-sampling for analysis or cool storage in a refrigerator for later use in the glasshouse experiment. Mineral and mineralisable nitrogen were determined on the 9-mm field-moist soils; for all other analyses, soils were air-dried and passed through a 2-mm sieve. For determination of organic carbon, total nitrogen, and total and inorganic phosphorus, samples were then ground to pass through a 0.25-mm sieve.

Soil acidity was determined in water, at a soil:water ratio of 1.0:2.5. Organic carbon was determined by the Walkley and Black colorimetric method as described by Nicholson (1984). Total nitrogen was determined colorimetrically (Searle 1975) after Kjeldahl digestion. Mineralisable nitrogen was determined in 1N potassium chloride extracts of soils (Bremner 1965) after incubation of field-moist samples in plastic bags at 25°C for 6 weeks. Inorganic and total phosphorus (Pi and Pt) were extracted in 1N sulphuric acid before (Pi) and after (Pt) ignition and determined in the extracts by the vanadomolybdate method (Kitson & Mellon 1944). Organic phosphorus (Po) was determined by the difference between inorganic and total phosphorus. Plant-available phosphorus was determined using the Bray-2 and Olsen methods as described by Nicholson (1984). Potassium, calcium, and magnesium were determined in the Bray-2 extracts by atomic absorption spectroscopy (Nicholson 1984). Aluminium was also determined by atomic absorption spectroscopy, after extraction in 1N potassium chloride. Sulphate-sulphur was determined in phosphate extracts using a barium sulphate turbidimetric method (Sinclair & Enright 1982).

Glasshouse Experiment

In the glasshouse experiment soils collected from under both vegetation types at all sites were placed in 1.6-*l* pots, and given one of four nutrient treatments:

(1) control = no nutrients added
(2) –P = all nutrients added except phosphorus

(3) –S, K, Ca, and Mg = all nutrients added except sulphur, potassium, calcium, and magnesium
(4) –N = all nutrients added except nitrogen.

Nutrients were added in solution to the soil surface after potting, at the following rates:

100 kg N/ha 100 kg P/ha 66 kg S/ha
125 kg K/ha 50 kg Ca/ha 50 kg Mg/ha
2 kg Mn/ha 2 kg Zn/ha 2 kg Fe/ha
1 kg Cu/ha 1 kg B/ha 1 kg Mo/ha.

White clover seedlings were planted in Treatments 1, 2, and 3. Ryegrass seedlings were planted in the treatment without nitrogen (Treatment 4). Five seedlings were planted in each pot and the shoots were harvested after 8 weeks' growth, oven-dried, and weighed. The experiment used a randomised block design with five replicates.

Foliar Analysis of Shrubs

At Cave Stream and Craigieburn canopy closure in the plantations had only recently occurred, and shrub species growing in the grasslands were also still present under the trees. To determine whether foliar nutrient composition was influenced by the presence of trees, four foliar samples were collected randomly in each of the two vegetation types from four species of shrub at each site. These were oven-dried and analysed for nutrient composition using the methods described by Nicholson (1984).

RESULTS

Soil Analyses

The main effect of site on soil chemical properties was highly significant for all analyses (Table 2). Data for the Lake Coleridge site were omitted from the analyses of variance because of its different site history (*see* Methods).

Soil pH

Mean soil pH was significantly lower under the conifers than under adjacent grassland (Table 2). However, at the three sites with the youngest stands, pH was either unaffected by vegetation type (Cave Stream and Lake Ida) or was slightly higher under the conifers (Craigieburn; Fig. 1a). These differences gave a significant site × vegetation type interaction, and there was a significant negative correlation between stand age and difference in soil pH between the two vegetation types ($r = -0.86$, $p<0.01$, $n = 8$). The greatest declines in pH occurred under the conifers in the Mackenzie Basin soils (declines of 0.4–0.8 pH units).

Organic carbon

Although mean organic carbon was not significantly affected by vegetation type (Table 2), levels were higher under the conifers at all the Mackenzie Basin sites and also at Lyndon Hill, whereas at Craigieburn and Lake Ida, and also at Lake Coleridge, levels were lower under the conifers (Fig. 1b). These differences resulted in a significant vegetation type × site interaction (Table 2).

TABLE 2–Effect of vegetation on topsoil chemical properties. Values are means of seven* sites, standard errors are shown in parentheses

Chemical property	Grassland	Conifer	Probability from ANOVA		
			Vegetation	Site	Interaction
pH	4.8 (0.10)	4.5 (0.10)	<0.001	<0.001	<0.001
Organic C (g/100 g)	4.8 (1.01)	4.8 (0.92)	n.s.	<0.001	<0.05
Total N (g/100 g)	0.30 (0.044)	0.26 (0.043)	<0.05	<0.001	n.s.
Mineralisable N (mg/kg)	8.0 (3.33)	9.0 (4.25)	n.s.	<0.001	<0.001
Sulphate-S (mg/kg)	4.9 (0.98)	13.5 (4.57)	<0.001	<0.001	<0.001
Total P (mg/100 g)	84 (8.0)	82 (7.3)	n.s.	<0.001	<0.05
Organic P (mg/100 g)	50 (9.1)	40 (8.8)	<0.001	<0.001	n.s.
Inorganic P (mg/100 g)	34 (5.2)	42 (6.1)	<0.001	<0.001	<0.05
Bray-2 P (mg/kg)	31 (13.4)	62 (24.1)	<0.001	<0.001	<0.001
Olsen P (mg/kg)	8 (2.5)	28 (10.9)	<0.001	<0.001	<0.001
Bray-2 K (me/100 g)	3.2 (0.70)	3.6 (0.58)	n.s.	<0.001	<0.001
Bray-2 Ca (me/100 g)	3.9 (0.71)	3.6 (0.80)	n.s.	<0.001	n.s.
Bray-2 Mg (me/100 g)	0.90 (0.149)	0.83 (0.146)	n.s.	<0.001	<0.05
Exchangeable Al (me/100 g)	0.99 (0.301)	1.64 (0.287)	<0.001	<0.001	<0.05

* The Lake Coleridge site was omitted from the analysis of variance, as it had been logged 7 years prior to sampling.

Total nitrogen

Mean total nitrogen levels were significantly lower under the conifers than under grassland (Table 2), but this difference was not apparent at all sites (Fig. 1c). Levels were slightly higher under the conifers at Benmore and Rhoborough Downs, and were similar at Lyndon Hill, but the vegetation type × site interaction was not significant.

Mineralisable nitrogen

Mean mineralisable nitrogen levels were not significantly different under the two vegetation types (Table 2), but there was a highly significant interaction between vegetation type and site. Levels were higher under the trees than under grassland at four of the five sites in Canterbury, whereas at Lyndon Hill and at the three Mackenzie Basin sites, levels were higher under the grassland (Fig. 1d). The largest increase under the trees occurred at Lake Coleridge, which had been logged 7 years before sampling, and may have been caused either by accelerated breakdown of litter after the site had been disturbed, or by the invasion of white clover.

Sulphate-sulphur

At all sites sulphate-sulphur levels were higher under the conifers than under the grasslands but there was a highly significant interaction between vegetation type and site (Table 2). The increase under the younger stands (Cave Stream, Craigieburn, and Lake Ida)

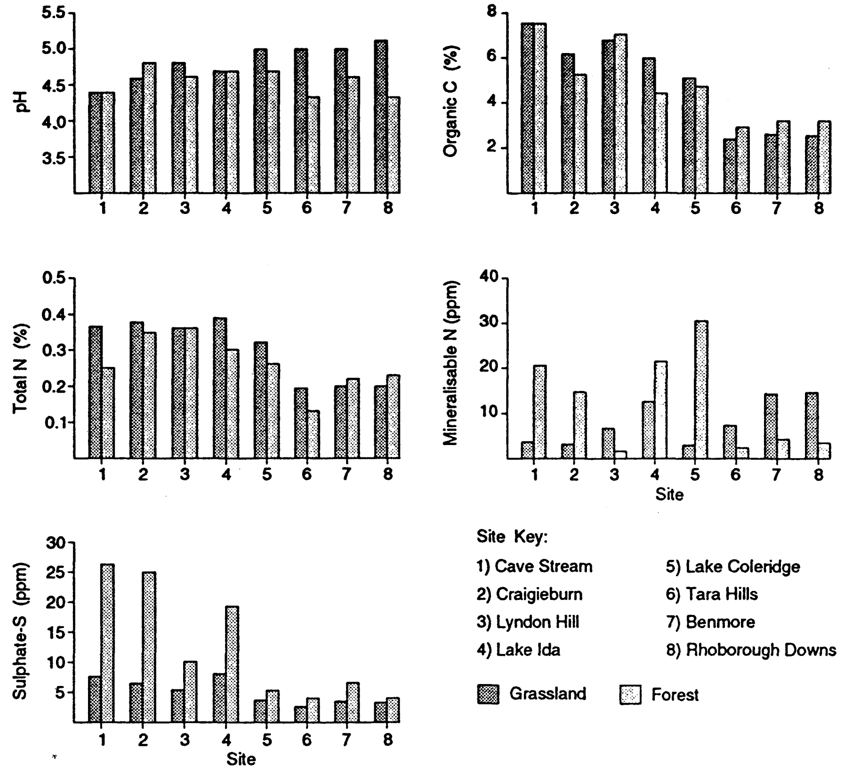

FIG. 1–Soil pH, organic carbon, total and mineralisable nitrogen, and sulphate-sulphur levels in topsoils from under pines and adjacent grasslands at eight high country sites.

was substantially higher than under the older stands (Fig. 1e). The increase in sulphate-sulphur levels declined linearly with increasing stand age up to about 30 years ($r = 0.97$, $p<0.01$, $n = 6$).

Phosphorus

Although mean total phosphorus levels were similar under the two vegetation types, organic phosphorus levels were significantly lower under the conifers than under grassland (the Benmore site was the only exception), and inorganic phosphorus levels were significantly higher (Table 2). Significant interactions occurred between vegetation type and site for both total phosphorus and inorganic phosphorus. Levels of total phosphorus were slightly lower under the conifers than under grassland at Cave Stream, Craigieburn, and Lake Ida (and also Lake Coleridge) but they were slightly higher at Tara Hills and Benmore (Fig. 2a). Inorganic phosphorus levels were higher under the conifers at all sites but there were differences in the magnitude of the increase (Fig. 2b).

Available phosphorus levels, as measured by both the Bray-2 and Olsen extractants, were significantly higher under the conifers than under grassland (Table 2). The interactions between vegetation type and site were also highly significant, as the positive influence of the

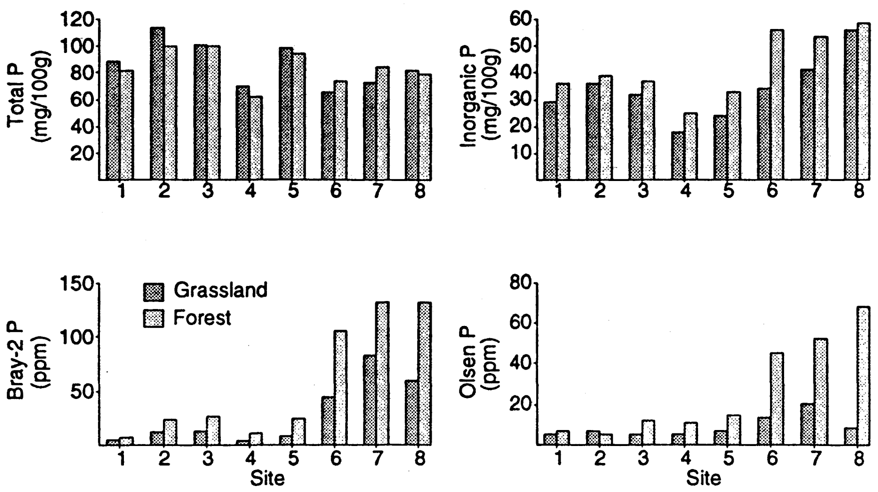

FIG. 2–Total, inorganic, and available phosphorus levels in topsoils from under pines and adjacent grasslands at eight high country sites. Site names are shown in Fig. 1.

conifers on soil phosphorus availability varied markedly between sites, with the absolute increases being much higher in the Mackenzie soils than in the Canterbury soils (Fig. 2c, d). However, with the Bray-2 test, the proportional increases were similar in the two groups; increases in Bray-2 available phosphorus levels under the conifers varied from 1.6- to 3.4-fold in the Canterbury soils, and from 1.6- to 2.4-fold in the Mackenzie soils. With the Olsen test the proportional increases were greater in the Mackenzie soils (2.7- to 8.4-fold) than in the Canterbury soils (0.8- to 2.3-fold).

The increases in available phosphorus levels under the conifers were positively correlated with stand age ($r = 0.83$ and 0.86, $p<0.01$, for the Bray-2 and Olsen tests respectively), and negatively correlated with change in soil pH ($r = -0.92$ and -0.91, $p<0.01$ respectively).

Bray-2 extractable cations

The main effect of vegetation type was not significant for Bray-2 extractable potassium, calcium, or magnesium, but for potassium and magnesium there were significant interactions between site and vegetation type (Table 2). These arose because both potassium and magnesium levels were higher under the conifers than under the adjacent grasslands in the Mackenzie soils while, with one exception (Lyndon Hill, potassium only), they were lower under the conifers in the Canterbury soils.

Exchangeable aluminium

Mean exchangeable aluminium levels were higher under the conifers than under grassland (Table 2). The one exception to this trend was at Craigieburn where the exchangeable aluminium level was lower under the conifers, and this caused a significant interaction between site and vegetation. This site was the only one where soil pH was higher under the conifers than under grassland. There was a significant correlation ($r = 0.83$, $p<0.01$) between the increase in exchangeable aluminium under the conifers and the decline in soil pH.

Glasshouse Experiment

Mean yields of white clover or ryegrass were significantly higher on soils collected from under conifers than under grassland in all four nutrient treatments (Table 3). Significant site × vegetation interactions were present in all treatments, indicating that, as with the soil analyses, the positive effect of the trees on grass and legume growth was strongly site-dependent.

TABLE 3 – Effect of vegetation type on the growth of white clover and ryegrass. Values (dry weights, g/pot) are means of eight sites

	White clover			Ryegrass
	Control	–P	–S, K, Ca, Mg	–N
Grassland	0.10	0.24	2.89	0.64
Conifer	0.52	1.32	3.80	1.64
Probability from ANOVA				
Vegetation	<0.001	<0.001	<0.05	<0.001
Site	<0.001	<0.001	<0.001	<0.001
Interaction	<0.001	<0.001	<0.01	<0.001

In the control (Treatment 1) where no nutrients were added, white clover grew better on soils collected from beneath trees than from grassland at Cave Stream, Lyndon Hill, Lake Coleridge, Benmore, and Rhoborough Downs, the differences being most apparent at the latter two Mackenzie Basin sites (Fig. 3a).

A similar pattern occurred in Treatment 2, where all nutrients except phosphorus were added, although the difference in clover growth between grassland and conifer soils was reduced in the Canterbury soils (absent at Cave Stream) and enhanced in the Mackenzie soils (Fig. 3b). The similarity between this treatment and the control indicates that the positive effect of the trees on white clover growth was caused largely by amelioration of phosphorus deficiency. White clover yields on the Mackenzie Basin soils in Treatment 2 were substantially higher than in the control, indicating a response by clover to a nutrient (or nutrients) other than phosphorus. The response is most likely to added sulphur, as both Mackenzie and Tasman soils are sulphur-deficient (N.Z. Soil Bureau 1968). By contrast, there was no response on the Canterbury soils, indicating that, for white clover, nutrients other than phosphorus were not deficient, or possibly that phosphorus deficiency was too acute to allow a response to other nutrients.

Where all nutrients except sulphur, potassium, calcium, and magnesium were added (Treatment 3), white clover grew better on soils from under conifers than from grassland at three sites—Lyndon Hill, Benmore, and Rhoborough Downs (Fig. 3b). With the better growth at the latter two sites, white clover developed sulphur-deficiency symptoms, indicating that the positive effect of the trees was not improved sulphur availability. The results of the soil analyses suggest that the response at these sites was most likely to improved potassium or magnesium availability. Alternatively, the response may still have been to alleviation of phosphorus deficiency, as the amount of phosphorus added in nutrient solution may have been insufficient to totally overcome the deficiency. In Canterbury, white clover

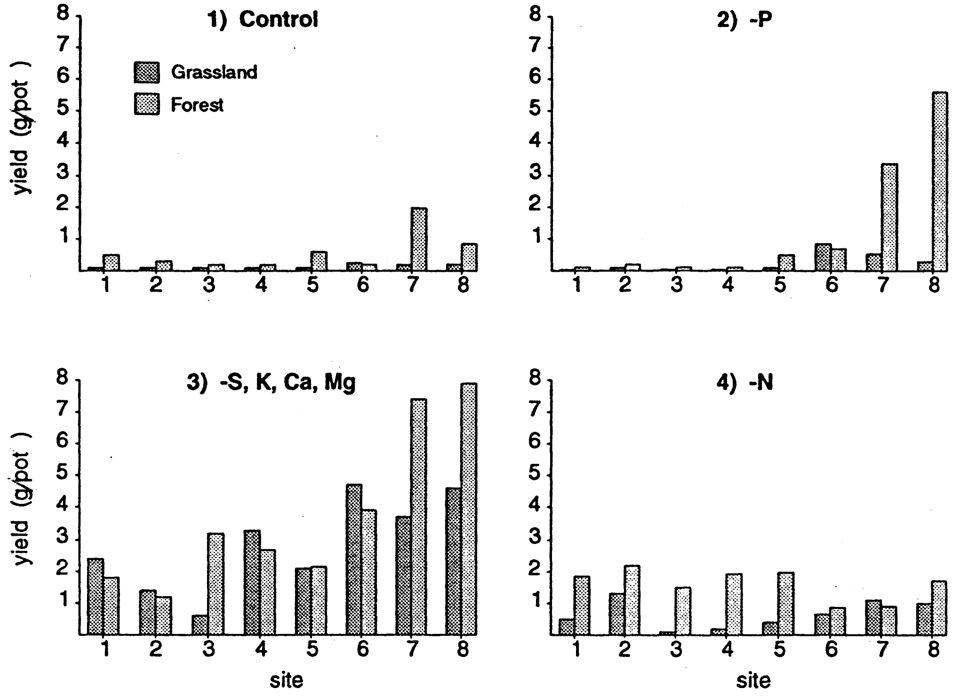

FIG. 3–Growth of white clover (Treatments 1, 2, and 3), and ryegrass (Treatment 4) in topsoils from under pines and adjacent grasslands at eight high country sites. Site names are shown in Fig. 1. Treatment 1, no nutrients added; Treatment 2, all nutrients added except phosphorus; Treatment 3, all nutrients added except sulphur, potassium, calcium, and magnesium; Treatment 4, all nutrients added except nitrogen.

showed a positive response to the presence of trees only at Lyndon Hill, and here the soil analyses suggest that the response was most likely to improved availability of sulphur. Yields of white clover on the grassland soils in Treatment 3 (i.e., in the presence of nitrogen and phosphorus) greatly exceeded those in either of the other two treatments in which white clover was grown, showing that, for clover, phosphorus deficiency was the major element limiting growth on all soils.

Where all nutrients except nitrogen were added (Treatment 4), ryegrass grew better on all of five soils collected from beneath conifers than from adjacent grassland in Canterbury, and also at Rhoborough Downs (Fig. 3d). For the Canterbury sites, with the exception of Lyndon Hill, the improved growth may be explained by the increased mineralisable nitrogen levels in those soils (Fig. 1c). However, it is not clear why ryegrass grew better on the soils from under the conifers at Lyndon Hill or Rhoborough Downs. Alleviation of sulphur and potassium deficiency respectively, as suggested for the improved growth of white clover on those sites in the treatment where all nutrients except sulphur, potassium, calcium, and magnesium were added, seems unlikely, as both nutrients were in the solution applied to ryegrass. Again, however, the amounts added may have been insufficient to overcome deficiencies totally.

Foliar Nutrients in Shrubs

At both the Cave Stream and Craigieburn sites, mean nitrogen, phosphorus, potassium, copper, and iron concentrations were higher in the foliage of shrubs growing under the trees than in those growing in the adjacent grassland (Table 4). Mean zinc and manganese concentrations were also higher in the shrubs under the trees at Craigieburn, but at Cave Stream zinc concentrations were lower and manganese concentrations were unaffected. Mean boron concentrations were lower in shrubs under the trees at both sites. The main effect of vegetation type was not significant for calcium or magnesium at either site.

TABLE 4–Effect of vegetation type on the foliar nutrient content of indigenous shrub species. Values are means of four species at each site

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)	B (ppm)	Mn (ppm)
Cave Stream										
Grassland	0.87	0.08	0.67	0.81	0.14	13.3	4.6	32	31	233
Conifer	1.19	0.11	0.86	0.78	0.11	11.1	6.5	41	23	261
Probability from ANOVA										
Vegetation	<0.001	<0.001	<0.01	n.s.	n.s.	<0.01	<0.01	<0.05	<0.001	n.s.
Shrub species	<0.001	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	<0.01	<0.001	<0.001
Interaction	<0.001	<0.001	n.s.	n.s.	n.s.	<0.01	<0.01	<0.05	<0.001	n.s.
Craigieburn										
Grassland	0.83	0.08	0.75	0.71	0.12	11.6	6.0	26	28	300
Conifer	1.16	0.13	1.01	0.78	0.13	14.4	8.6	37	22	389
Probability from ANOVA										
Vegetation	<0.001	<0.001	<0.001	n.s.	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001
Shrub species	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.01	<0.001	<0.001
Interaction	<0.001	<0.001	<0.05	<0.01	n.s.	n.s.	n.s.	n.s.	<0.001	n.s.

Significant interactions between vegetation and site occurred with a number of the analyses (Table 4). These were sometimes caused only by differences between species in the magnitude of their response to the presence of the trees, as for nitrogen at both sites and phosphorus at Craigieburn (Fig. 4a, b). At Cave Stream, the interactions for phosphorus, copper, and iron occurred largely because concentrations of these elements in *Leptospermum scoparium* Forst. were no higher under the trees than out in the open, in contrast to the other species (Fig. 4b, d, e). A similar pattern for potassium at Cave Stream (Fig. 4c) was not significant, but at Craigieburn the interaction for potassium was significant, because of the nil response by *Hebe pinguifolia* (Hook. f.) Ckn. et Allan. The interaction for zinc at Cave Stream occurred because two species (*Hebe venustula* (Col.) L.B.Moore and *Cassinia fulvida* Hook. f.) contained markedly lower concentrations under the trees than in the open, but there was little difference between the two vegetation types for the other two species. The interactions for boron at both sites resulted from the much lower concentrations in *C.fulvida* under the trees than in the open compared to the other shrubs, which were largely unaffected (Fig. 4f).

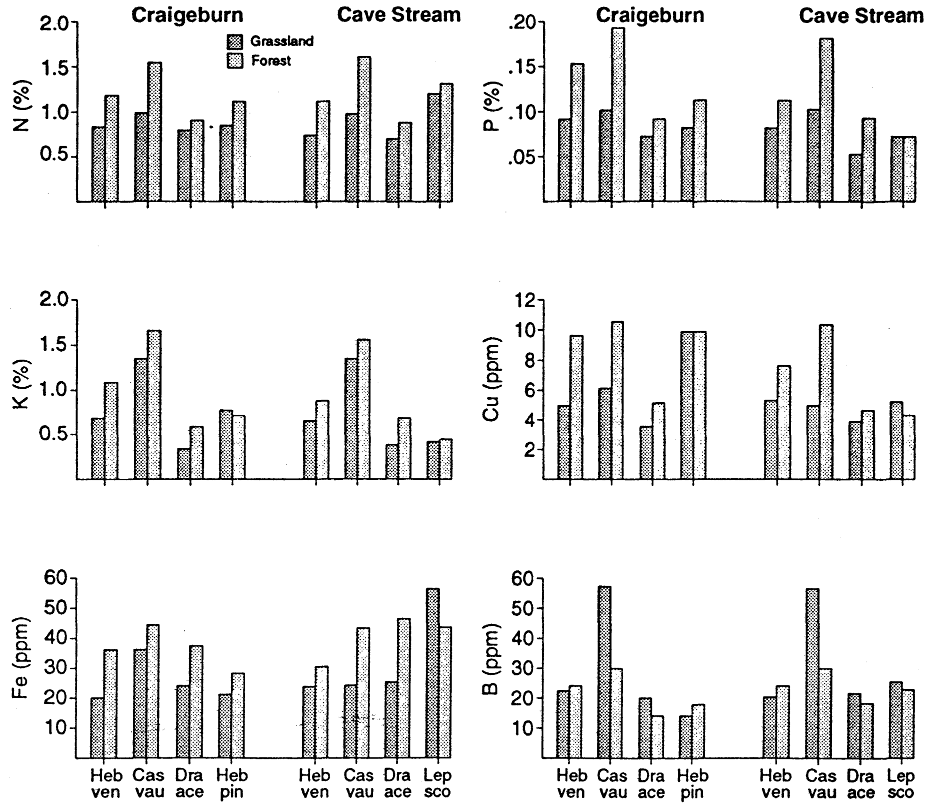

FIG. 4–Nutrient concentrations in shrubs growing under young conifer stands and in adjacent grasslands at two sites in Canterbury. Shrub species are: Heb ven, *Hebe venustula*; Cas vau, *Cassinia vauvilliersii*; Dra ace, *Dracophyllum acerosum*; Heb pin, *Hebe pinguifolia*; and Lep sco, *Leptospermum scoparium.*

DISCUSSION

The results of this study support those of other work (Ledgard & Belton 1985; Belton *et al.* in prep.) which have shown that inorganic and available phosphorus levels are higher under conifer stands than under grassland in the South Island high country region. In addition, the soil analyses show that levels of mineralisable nitrogen, sulphate-sulphur, potassium, and magnesium may also be higher under conifers. The shrub analyses provide additional support for these results, and further indicate that the availability of all micronutrients except boron may be improved under conifers.

Enhanced nutrient levels in soils under trees compared to grassland or other adjacent vegetation have been reported by other authors. In New York State in the United States, mineral nitrogen and readily soluble phosphorus levels were higher in soils beneath several *Larix* and *Pinus* plantations than in soils under the abandoned field vegetation in which they had been planted (Fisher & Stone 1969). Herbaceous plants growing beneath or near the conifers also had higher nitrogen and phosphorus concentrations and greater dry weight. In Nevada, concentrations of exchangeable cations, extractable phosphorus, sulphur, and micronutrients, and mineralisable nitrogen, were all higher in soils under single *Pinus monophylla* Torr. et Frem. tree crowns than in the soils between trees (Everett *et al.* 1986). Total phosphorus content of soils under *Betula* spp. planted on heather moorland in northern England and Scotland was substantially higher than in unplanted soils (Harrison *et al.* 1988).

At all of the Canterbury sites except Lyndon Hill, the soils under the conifers were characterised by having lower total nitrogen, total phosphorus, and organic phosphorus levels than adjacent grassland, but much higher mineralisable nitrogen and sulphate-sulphur levels. The higher levels of mineralisable nitrogen in these soils must have arisen from mineralisation of organic matter by the conifers, and it seems likely that the higher sulphate-sulphur and inorganic and available phosphorus levels in these soils under the conifers arose, at least in part, from mineralisation of organic matter. Fisher & Stone (1969) have suggested that mineralisation of soil organic compounds by conifer roots was the most likely reason for elevated levels of nitrogen and phosphorus in soils under several young conifer stands in New York State. Similarly, McIntosh (1980) attributed lower levels of organic phosphorus under *Pinus radiata* than under adjacent *Leptospermum* shrubland (Kaingaroa Forest, New Zealand) to organic matter mineralisation by the pine.

At Lyndon Hill and the three Mackenzie Basin sites there was much less evidence of increased mineralisation of organic matter under the conifers. Only at Tara Hills was total nitrogen and organic phosphorus substantially lower under the conifers. Organic carbon was slightly higher under the conifers at all of these sites, at two of them total nitrogen and total phosphorus were also slightly higher, and mineralisable nitrogen was higher in the grasslands at all four sites. These results, coupled with the very much higher increases in available phosphorus in the Mackenzie soils than in Canterbury soils, suggest that some other mechanism, such as nutrient pumping (i.e,, exploitation by trees of nutrients in subsoils or deeper materials, and their return to the surface in litter), might be responsible for the elevated inorganic and available phosphorus levels at these sites.

Lyndon Hill differed from the other Canterbury sites in that it was the only site with a high stone content in the topsoil, and it was also located on a steep (25°) slope. These factors would lead to a lower overall soil moisture status than the other Canterbury sites, and may explain why changes in soil organic carbon and total and mineralisable nitrogen contents under the conifers were more like those for the drier Mackenzie Basin sites.

The significant linear correlations between stand age and both degree of pH decline under the trees and increase in available phosphorus levels suggest that age is an important factor in determining the magnitude of change in these soil properties. However, these relationships are compromised as three of the four oldest stands were located in the Mackenzie Basin, and the youngest stands were all located in Canterbury. More comparisons of soils under stands of different ages with soils of the adjacent grasslands are needed before the effect of stand age on soil chemistry can be evaluated fully. The availability of such stands is limited.

In the glasshouse trial, the better growth of ryegrass and white clover on soil collected from under the trees generally supported and could be explained by the results of the soil analyses, but there were two major exceptions. Firstly, in the minus phosphorus treatment, white clover failed to show any response to the elevated phosphorus levels in the plantation soil from Tara Hills, in contrast to the pronounced responses observed from the other two Mackenzie Basin sites. It is not clear why white clover failed to respond to the elevated phosphorus levels at Tara Hills as it showed a strong response, presumably to phosphorus, in the treatment where all nutrients except sulphur, potassium, calcium, and magnesium were added. Secondly, in the treatment where all nutrients except nitrogen were added, ryegrass grew better in the soil collected from under the trees at Lyndon Hill, despite the soil analyses showing no indication of elevated mineralisation nitrogen levels. Again, it is not clear why this discrepancy occurred, but the response suggests that the trees had improved some soil factor other than mineralisable nitrogen for grass growth.

The soil analyses and the glasshouse experiment indicated that much smaller increases in absolute levels of available phosphorus occurred under the Canterbury stands than under the Mackenzie Basin stands. However, the increases in foliar phosphorus concentrations in the shrubs under the younger stands at both Cave Stream and Craigieburn show that phosphorus availability must have been increased substantially there. Bray-2 and Olsen phosphorus levels were much lower in the Canterbury soils than in the Mackenzie soils, and the limited increases in phosphorus availability under the conifer stands in the Canterbury region may therefore simply reflect a high demand on a smaller available phosphorus pool than that in the Mackenzie soils.

Increases in phosphorus concentration in shrub foliage were recorded under conditions of low phosphorus availability and high demand from the conifers indicating that phosphorus transfer from the source to the conifers is indirect. This phosphorus must exist, at least for a short period, in a pool that is available to other plant species in the ecosystem. Such phosphorus would presumably be available for capture by pasture grasses and legumes growing in an agroforestry system.

CONCLUSIONS

The montane zone on the eastern side of South Island has traditionally been used for extensive pastoralism, but pasture production is commonly limited by severe deficiencies of phosphorus, sulphur, and, for grasses, nitrogen. In the same areas conifers are capable of good growth rates in the absence of fertilisers and no deficiencies of these elements have been reported for conifer growth, although few fertiliser trials have been undertaken. The results reported here indicate that, in addition to having access to nutrients that seem largely unavailable to pasture species, conifers appear able to increase the availability of these and other nutrients to pasture plants. There may therefore be scope for the development of agroforestry systems to take advantage of this nutrient enrichment, and particularly for incorporating legumes into the system to make use of the increased phosphorus availability to improve soil nitrogen levels.

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REFERENCES

BELTON, M.C.; O'CONNOR, K.F.; ROBSON, A.B.: Influence of forest plantations on topsoil phosphorus levels in New Zealand montane soils. *Soil Use and Management* (in prep.).

BREMNER, J.M. 1965: Inorganic forms of nitrogen. Pp. 1179–206 *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 Inc., Madison, Wisconsin, Agronomy Series No. 9.*

EVERETT, R.; SHARROW, S.; THRAN, D. 1986: Soil nutrient distribution under and adjacent to singleleaf pinyon crowns. *Soil Science Society of America Journal 50*: 788–92.

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*: 955–61.

HARRISON, A.F.; MILES, J.; HOWARD, D.M. 1988: Phosphorus update by birch from various depths in the soil. *Forestry 61*: 349–58.

KITSON, R.E.; MELLON, M.G. 1944: Colorimetric determination of phosphorus as molybdovanadophosphoric acid. *Industrial and Engineering Chemistry, Analytical Edition 16*: 379–83.

LEDGARD, N.J.; BELTON, M.C. 1985: Exotic trees in the Canterbury high country. *New Zealand Journal of Forestry Science 15*: 298–323.

McINTOSH, P.D. 1980: Soil changes under radiata pine in Kaingaroa Forest, central North Island, New Zealand. *New Zealand Journal of Science 23*: 83–92.

N. Z. SOIL BUREAU 1968: Soils of the South Island, New Zealand. *New Zealand Soil Bureau Bulletin 27.*

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

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*: 183–7.

SINCLAIR, A.G.; ENRIGHT, P.D. 1982: An autoanalyser method for the determination of extractable soil sulphate using automated purification of extracts. *New Zealand Journal of Science 25*: 141–6.