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SOIL DEVELOPMENT UNDER PINUS RADIATA AND EUCALYPTUS REGNANS PLANTATIONS

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ABSTRACT

The weight of the forest floor under **Pinus radiata** D. Don averaged about double that under **Eucalyptus regnans** F. Muell. up to age 17 years. The concentrations of nitrogen, phosphorus, and potassium were higher and of calcium lower in the forest floor under pine. Differences in mineral soil nutrient status had apparently developed by age 4 years with more total nitrogen and exchangeable calcium but less exchangeable magnesium in the top 40 cm of soil under **E. regnans** than under **P. radiata**.

Keywords: soil; forest floor; nutrients; **Pinus radiata**; **Eucalyptus regnans**.

INTRODUCTION

Trees are known to affect the soils on which they are growing. In New Zealand the effects of introduced species on the soil have not been widely studied (Will & Ballard 1976). In Australia soils under planted *Pinus radiata* have been compared with those under native eucalypt forests. Lewis & Harding (1963) found no significant difference in soil chemical characteristics under *P. radiata* aged at least 27 years and *E. baxteri* (Benth.) Maid. & Blakely though acidity of and nitrogen concentrations in the top 2.5 cm of mineral soil tended to be greater under the pine. Hamilton (1965) found that 19 to 31 years after planting *P. radiata* on dry sclerophyll sites there were decreases in loss on ignition and nutrients in the surface 2.5 cm of soil. Only one wet sclerophyll site was studied. Hopmans *et al.* (1979) found lower acidity and water-soluble phosphorus under 27-year-old *P. radiata* than under *E. baxteri* and *E. viminalis* Labill. Turner & Kelly (1985) compared soils under two >40-year-old *P. radiata* plantations and adjacent mixed *Eucalyptus* forests and found different results at the two sites, which may have been due to differences in the fire history of the two *Eucalyptus* stands.

In New Zealand both *P. radiata* and *E. regnans* are introduced species. A comparison of 8-year-old plantations of the two species indicated a forest floor weight under the pine which was more than double that under the eucalypt, with higher accumulations of nitrogen, phosphorus, potassium, calcium, and magnesium (Frederick *et al.* 1985a). Mineral soil under the eucalypt contained a larger amount of nitrogen to a depth of 40 cm.

This paper reports a comparison of litter layers and mineral soil conditions under paired plantations of *P. radiata* and *E. regnans* ranging in age from 4 to 17 years.

MATERIALS AND METHODS

Field Procedures

All sample stands were located on lands of N.Z. Forest Products Ltd in the central North Island near Mangakino. Stands of *E. regnans* aged 4, 7, 8, 10, 13, and 17 years were chosen to represent typical operational plantings by N.Z. Forest Products Ltd on well-drained pumice soils. Adjacent stands of *P. radiata* of the same age were chosen for comparison. Soil in the 4-, 7-, 8-, and 13-year-old stands was Taupo sandy loam composed of Taupo pumice plus older tephras, while in the 10- and 17-year-old stands the soil was Ngakuru sandy loam composed of fine tephra (N. Kennedy, pers. comm.).

Each stand was sampled for structure and stocking using a randomly located 20 × 20-m (0.04-ha) plot. Diameters of all trees were measured and heights were measured on a sample of 7 to 10 trees over the diameter range in each plot, depending on stocking. Dry weights and nutrient contents of the *E. regnans* and the 8-year-old *P. radiata* stands have already been reported (Frederick *et al.* 1985a, b). Stem weights of the other pine stands were estimated using the equation by Madgwick (1985).

The forest floor was sampled on ten 0.25-m^2 quadrats randomly located in each plot. Three composite mineral soil samples of nine cores each were obtained from the 0–20 and 20–40 cm depth in each stand using a 2.5-cm-diameter tube sampler. Bulk density was determined on five cores per plot using a 5-cm-diameter sampler.

Laboratory Procedures

Forest floor samples were oven-dried at 70°C, weighed, and ground to pass a 1-mm sieve prior to chemical analysis. Mineral soils were air-dried and sieved to pass a 2-mm screen.

All material was analysed using standard FRI methods (Nicholson 1984). Subsamples of forest floor were digested, using sulphuric acid and hydrogen peroxide in the presence of lithium sulphate and selenium. Nitrogen was determined by the indophenol-blue and phosphorus by the vanadomolybdate method. Potassium, calcium, and magnesium were determined by atomic absorption. Soil nitrogen was determined by Kjeldahl digestion, available phosphorus by the Bray No. 2 extraction, and exchangeable calcium, magnesium, and potassium after leaching with neutral normal ammonium acetate.

Carbon was estimated by a modified Walkley-Black chromic acid digestion. The pH of the mineral soil was determined electrometrically on air-dried samples using a ratio of 1 : 2.5 soil : water. Loss on ignition was obtained after heating at 500°C for 1 hour.

For each species, between-plot differences in results were analysed using analysis of variance. Between-species effects were examined using differences between plot values for each age pair of plots.

RESULTS AND DISCUSSION

Basal area of *E. regnans* stands ranged from 19 to 65 m^2/ha and for *P. radiata* from 13 to 56 m^2/ha (Table 1). Site index based on an index age of 20 years was about 40 m for *E. regnans* (Webb 1965). For *P. radiata* site index according to the curves of Burkhart & Tennent (1977) was very variable, ranging from 27 m for the 17-year-old stand to over 36 m for younger stands. Basal area, height, and stem weight of *E. regnans* stands were each greater than for *P. radiata* of corresponding age.

The weight of the forest floor under *E. regnans* varied between 4.7 and 11.0 tonnes/ha with little effect of stand age (Table 2). Litterfall in these stands averaged 7.8 t/ha/annum (Frederick *et al.* 1985b). The similarity of litterfall and forest floor weights indicates that a quasi-stable forest floor was achieved early in the life of the *E. regnans* stands. Under *P. radiata* the weight of the forest floor increased with age from 4 to 8 years after which the mean weight was 18.7 t/ha which is about the value expected at around age 20 in central North Island plantations (Carey *et al.* 1982). Litterfall under *P. radiata* was measured in the 8-year-old stand where it was 6.2 t/ha/annum (Frederick *et al.* 1985a). Decomposition rates are clearly lower under *P. radiata* than under *E. regnans*.

Nutrient concentrations in the forest floors varied significantly between species with *P. radiata* having higher nitrogen, phosphorus, and potassium but lower calcium than *E. regnans* (Table 2). The difference in magnesium concentration between species was not significant. Loss on ignition and carbon/nitrogen ratios were lower under pine than eucalypt. Nutrient concentrations in the forest floor were not related to stand age.

Soil pH and exchangeable potassium concentrations were higher in the surface 20 cm of mineral soil under *P. radiata* than under *E. regnans* (Table 3). Loss on ignition and cation exchange capacity were higher under *E. regnans*. These relative differences between *P. radiata* soils and those under *Eucalyptus* are similar to those found by Hamilton (1965) for the surface 2.5 cm of soil where *P. radiata* had been planted on natural, dry sclerophyll *Eucalyptus* sites except that Hamilton found no consistent effect on acidity. The one wet sclerophyll site studied by Hamilton was probably more similar to our sites but did not exhibit the same species effects found on dry sites. Under Australian conditions Baker (1983) found higher returns of nitrogen in litterfall under *Eucalyptus*, which could account for differences in soil nitrogen under the two genera, but the limited data from New Zealand (Frederick *et al.* 1985a) indicated similar litterfall nitrogen content for the two species. In our stands the differences between species were not greatly affected by plantation age. Differences between species in the 20–40 cm mineral soil layer were not significant owing to exceptional conditions in the 17-year-old stands.

TABLE 1—The stocking, basal area, average height, and estimated stem weight of an age series of ***E. regnans*** and ***P. radiata*** stands. Stem weights based on Frederick ***et al.*** (1985a, b) and Madgwick (1985), respectively.

Age (years)	***E. regnans***					***P. radiata***				
	Stocking (stems/ha)	Basal area (m^2/ha)	Height		Stem weight (t/ha)	Stocking (stems/ha)	Basal area (m^2/ha)	Height		Stem weight (t/ha)
			Mean (m)	Top (m)				Mean (m)	Top (m)	
4	2050	19.3	11.6	14.5	47.5	2059	12.9	6.8	8.9	18.7
7	1850	45.7	19.5	22.2	157.7	1396	33.5	14.3	16.0	84.3
8	2150	39.1	17.6	20.0	134.3	1775	32.9	12.3	15.0	68.6
10	1075	58.5	22.7	26.3	262.0	1320	55.7	14.7	16.2	132.3
13	1300	53.9	23.8	30.7	248.0	1293	43.7	15.7	20.7	115.4
17	1250	65.0	29.5	37.2	409.7	721	50.3	20.8	23.3	167.7

TABLE 2—The oven-dry weight, loss on ignition, nutrient concentrations, and carbon-nitrogen ratio of the forest floor. Within a species, values in any column followed by the same letter are not significantly different using Least Significant Difference and a 5% probability level. Species effects: n.s. not significant; + **P. radiata** > **E. regnans**; - **E. regnans** > **P. radiata**; one, two, and three symbols represent 5%, 1%, and 0.1% levels

Age (years)	Weight (t/ha)	Loss on ignition (%)	N	P	K	Ca	Mg	C/N
			(%)					
E. regnans								
4	4.9a	91a	1.04a	0.080a	0.11a	1.5a	0.15a	38a
7	5.0a	89a	1.00a	0.076ab	0.13a	1.1b	0.14a	40a
8	9.2bc	90a	0.93a	0.072ab	0.10a	1.1b	0.11c	47ab
10	7.8b	88a	1.02a	0.091c	0.12a	1.5a	0.14a	39a
13	4.7a	89a	1.01a	0.076ab	0.16a	1.0b	0.17b	41a
17	11.0c	92a	0.75b	0.064b	0.10a	0.7c	0.11c	56b
P. radiata								
4	7.0a	75a	1.45a	0.114cd	0.17ab	0.8ab	0.11a	25ab
7	14.6b	92b	1.55a	0.097ab	0.14a	0.5a	0.13ab	29c
8	18.9b	89bc	1.43a	0.086a	0.16ab	0.6a	0.12a	29c
10	21.0b	71a	1.45a	0.122d	0.19b	0.7ab	0.09ab	23a
13	18.4b	81abc	1.46a	0.104bc	0.17ab	1.0b	0.18b	28bc
17	16.5b	80ac	1.48a	0.110bcd	0.17ab	0.6a	0.08c	27abc
Species effects								
	++	-	+++	++	+	-	n.s.	---

Total volatile matter and nutrient contents of the forest floor were significantly greater for *P. radiata* than *E. regnans* except for calcium (Table 4). Regression analysis indicated that the differences between the forest floors under the two species increased with stand age. These results reflect the greater dry weight of the forest floor under *P. radiata* and differences between the two species in the nutrient concentrations within forest floor material.

For mineral soil there was a large difference among plots in total nitrogen content of the top 40 cm of soil but these differences were not related to stand age or soil type (Table 5). There was more total nitrogen and exchangeable calcium but less exchangeable magnesium under *E. regnans* than under *P. radiata*. The differences in magnesium increased with stand age but the difference in calcium content decreased with stand age. Differences among plots in bulk density of the surface 40 cm of mineral soil imply that total nutrient contents are based on different weights of soil from plot to plot so care must be exercised in interpreting the results.

TABLE 3—Loss on ignition (L.O.I.), bulk density, cation exchange capacity (C.E.C.), pH, and nutrient concentrations of soils under an age series of **E. regnans** and **P. radiata** stands. Within each column for each species and depth, values followed by the same letter are not significantly different using Least Significant Difference and a 5% probability level. Species effects: n.s. not significant; + **P. radiata** > **E. regnans**; - **E. regnans** > **P. radiata**; one and two symbols represent 5% and 1% levels

Age (years)	L.O.I. (%)	Bulk density (g/cc)	C.E.C. (m.e. %)	pH	Total N (%)	Bray P (ppm)	Exchangeable K (m.e. %)	Exchangeable Ca (m.e. %)	Exchangeable Mg (m.e. %)
E. regnans 0–20 cm									
4	13.8a	0.64a	41a	5.61a	0.28abc	28a	0.41bc	3.5a	1.1a
7	14.3a	0.51a	41a	5.93b	0.31abc	21ab	0.44bc	5.5ab	1.4a
8	11.1a	0.62a	28a	5.50a	0.23a	14ab	0.30ab	2.0a	0.6a
10	15.5a	0.61a	47a	5.47a	0.41c	19ab	0.24a	3.1a	0.5a
13	16.3a	0.63a	49a	5.64a	0.37bc	17ab	0.61d	9.4b	3.1b
17	14.0a	0.47a	40a	5.56a	0.27ab	7b	0.54cd	3.4a	1.4a
P. radiata 0–20 cm									
4	10.3a	0.68a	27ab	6.04a	0.19a	12ab	0.64ab	2.7a	0.7a
7	13.8ab	0.53a	33bc	5.76ab	0.29ab	10ab	0.62ab	3.3a	0.8a
8	9.7a	0.70a	28abc	5.97ab	0.18a	12ab	0.47a	2.8a	0.8a
10	12.0ab	0.65a	36cd	5.86ab	0.32b	6a	0.69ab	4.3a	0.9a
13	16.5b	0.51a	45d	5.93ab	0.41b	5a	0.92b	11.5b	3.5b
17	9.0a	0.60a	20a	5.71b	0.18a	18b	0.53a	1.7a	0.4a
E. regnans 20–40 cm									
4	7.5ab	0.70a	22ab	5.65a	0.11ab	11a	0.49a	0.9ab	0.35a
7	8.4b	0.68a	23ab	6.05c	0.15b	13a	0.47a	1.4b	0.46ab
8	5.2a	0.78a	16a	5.80ab	0.07a	21a	0.49a	0.5a	0.22a
10	9.7b	0.77a	34b	5.67ab	0.17b	3a	0.23a	1.3b	0.25a
13	9.3b	0.68a	33b	5.90bc	0.17b	9a	0.57a	2.9c	1.26b
17	8.0ab	0.59a	26ab	5.69ab	0.14b	4a	0.54a	1.1b	0.49ab
P. radiata 20–40 cm									
4	9.9bc	0.71a	32b	5.85a	0.18bcd	9a	0.46a	1.5a	0.36a
7	7.3abc	0.65a	22ab	5.80a	0.11abc	11ab	0.50a	0.9a	0.27a
8	5.5ab	0.79a	24abc	5.99a	0.09ab	15ab	0.37a	0.6a	0.18a
10	11.3c	0.71a	35c	5.98a	0.20cd	2a	0.53a	1.6a	0.52a
13	10.4c	0.61a	34c	5.92a	0.21d	3ab	0.59a	6.7a	1.44b
17	3.9a	0.73a	14a	5.91a	0.05a	17b	0.64a	0.5a	0.11a
Species effects									
0-20cm	-	n.s.	-	+	n.s.	n.s.	++	n.s.	n.s.
20-40cm	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

TABLE 4—Total volatile matter and nutrients in the forest floor of an age series of **E. regnans** and **P. radiata** plantations. Species effects: n.s. not significant: + and ++ **P. radiata** > **E. regnans** at the 5% and 1% levels, respectively

Age (years)	Volatile matter (t/ha)	N	P	K (kg/ha)	Ca	Mg
E regnans						
4	4.4	51.0	3.9	5.5	76.2	7.2
7	4.5	51.1	3.8	6.4	57.5	7.1
8	8.3	87.2	6.7	8.9	104.1	10.3
10	7.0	80.1	7.2	8.9	120.7	10.8
13	4.2	46.8	3.5	7.4	48.5	8.0
17	10.1	82.7	7.1	10.6	75.8	12.5
P. radiata						
4	5.3	101.5	8.0	12.4	52.8	7.6
7	13.4	223.2	14.1	20.2	78.7	19.2
8	17.0	271.1	16.4	29.8	120.5	24.6
10	15.0	306.2	25.3	38.3	149.4	19.7
13	14.9	269.7	19.1	31.5	181.5	32.3
17	13.3	243.6	18.1	28.3	103.2	13.3
Species effects	++	++	++	++	n.s.	+

TABLE 5—Total nitrogen, Bray-2 phosphorus, and exchangeable potassium, calcium, and magnesium in the surface 40 cm of mineral soil in an age series of **E. regnans** and **P. radiata** plantations. Species effects: n.s. not significant; + **P. radiata** > **E. regnans** at the 5% significance level; - **E. regnans** > **P. radiata**

Age (years)	Total N (t/ha)	Bray-2 P (kg/ha)	K	Exchangeable Ca (kg/ha)	Mg
E regnans					
4	4.36	44	418	959	193
7	4.45	34	375	1308	223
8	3.51	44	377	594	117
10	6.10	23	219	945	102
13	6.02	30	539	2691	580
17	3.67	10	392	786	197
P. radiata					
4	4.52	26	1023	152	525
7	3.98	22	819	128	441
8	2.72	29	353	628	104
10	5.81	8	1305	195	462
13	5.59	7	3330	542	541
17	2.48	42	487	61	566
Species effects	-	n.s.	n.s.	-	+

Our results indicate that considerable differences can develop in the soil profile under pine and eucalypt stands within a few years of stand establishment. The current knowledge of soil nutrient relationships is such that we cannot safely predict what these differences mean for the long-term productivity of forest soils. Two steps in the examination of the implications of widespread planting of introduced species are suggested. First, replicated experiments should be established using different species on a range of sites with measurement of soil conditions over time. Sampling over smaller depth zones would improve the likelihood of early detection of soil changes. Second, such experimental plots should be clearfelled and replanted to establish the effects of induced soil changes on the growth of subsequent forests of the same and of different species.

CONCLUSIONS

Compared with *E. regnans,* mineral soils under *P. radiata* contained less total nitrogen and exchangeable calcium but more exchangeable magnesium while the forest floor under pine contained more nitrogen, phosphorus, potassium, and magnesium. These differences were expressed even in the 4-year-old stands. The faster decomposition of litter and the early attainment of a stable forest floor under *E. regnans* compared with under *P. radiata* indicates marked differences in nutrient dynamics between the two species. The effect of introduced forest species on soil properties has received relatively little attention in New Zealand in spite of the large areas of new planting. We recommend investigation of the first few years after stand establishment to elucidate factors affecting soil changes.

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