SOIL PROPERTIES AS AFFECTED BY PINUS RADIATA PLANTATIONS

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(Received for publication 11 February 1987; revision 18 August 1987)

ABSTRACT

Soils beneath planted **Pinus radiata** D. Don were compared with soils beneath adjacent native **Eucalyptus** forest at two sites with contrasting nutrient status in New South Wales. At the lower fertility site, the soil under **P. radiata** was lower in nitrogen, exchangeable magnesium, and pH and higher in organic matter and exchangeable aluminium than soil under native forest. An apparent deficit in total nitrogen in the pine ecosystem could be accounted for by the quantity in thinnings. At the higher fertility site, the soil under pine had lower concentrations of nitrogen and organic matter than that under native forest, but was not significantly different in other respects. As reported in similar studies, organic matter content appeared to be the main soil property influenced by plantation establishment; this effect was more pronounced at the poorer site where rooting depth was limited to 30–40 cm by a sharp change in texture.

Keywords: soil nutrients; biomass; podsolisation; site productivity; **Pinus radiata.**

INTRODUCTION

Pinus radiata is an efficient wood-producing species and is planted extensively in countries such as Australia, New Zealand, and Chile (Turner & Lambert 1986b). Concern has been expressed about the possible deleterious effects of pine planting on soil properties, and in particular it has been suggested that *P. radiata* is a strongly podsolising species (Hamilton 1965; Routley & Routley 1975; Calvo & Diaz-Fierros 1981; Khanna & Ulrich 1984). However, no evidence has been produced, using standard methods of chemical analysis of soils, that *P. radiata* plantations have led to greater podsolisation of soil than that which resulted from the natural forests which preceded them (Feller 1978; Calvo *et al.* 1979a; Hopmans *et al.* 1979; Turner & Kelly 1985). Despite the lack of evidence for accelerated podsolisation, there is a need for further study of soils under *P. radiata* plantations so that processes related to long-term nutrient availability and maintenance of productivity can be further understood (Skinner & Attiwill 1981a, b).

Study of forest species' effects on soil properties presents certain difficulties. Firstly, there is the problem of separation of effects of species, such as accelerated nutrient leaching, from those effects due to management practices, e.g., nutrient removals in harvesting, or compaction due to equipment usage. Secondly, there is the selection of appropriate study methods to determine impacts. Precedents exist in the literature for both long-term and shorter-term methods. Long-term studies on soil properties have been carried out in relation to fertiliser effects on soils under *P. radiata* (Gentle *et al.* 1965, in press; Turner & Lambert 1986a), and other conifers planted on degraded agricultural areas (Gilmore & Boggess 1976); in these situations there were large changes in nutrient status. Effects of species may be studied concurrently over a long period of time but, generally, information on possible effects is required in a much shorter time period and such a method is unsuitable. Alternatively, soils beneath exotic conifers may be compared with those under adjacent vegetation similar to that existing prior to establishment of the conifer stand (Turner & Kelly 1977, 1985; Hopmans *et al.* 1979; McIntosh 1980). In such a study, the measurable effects will depend upon the characteristics of the native vegetation compared with the planted species and the degree of spatial variability. A third method (Page 1968) entails the study of soil changes which take place as a stand of an exotic species matures, specifically at the time of maximum litter accumulation. This method overcomes a potential problem in other comparison techniques – namely, that differences may have existed in soil properties prior to conifer planting.

In the present study, the properties of soils beneath *P. radiata* plantation stands and adjacent stands of *Eucalyptus* spp. were compared at two markedly different sites in New South Wales. The results are discussed in relation to other similar studies, in addition to potential management impacts.

SITE AND METHODS

Two sites with contrasting nutrient status were selected for study. A *P. radiata* stand and adjacent eucalypt woodland at Lidsdale State Forest on the New South Wales central tablelands were selected as representing a low-nutrient site. The higher-nutrient site was at Nundle State Forest on the New South Wales northern tablelands (Fig. 1). Details of both sites are given in Table 1. The location at Lidsdale State Forest is on soils derived from Devonian shale. The soils that have developed are yellow podsolics and are low in both phosphorus and calcium. The native eucalypt species (predominantly *Eucalyptus dives* Schau. and *E. maculosa* R.T. Bak.) form a woodland in which there are no trees of commercial value. Both sites were originally cleared for grazing purposes but this produced low-quality pasture and they were subsequently planted in pine or allowed to regenerate to native species. No fertilisers were applied to either the eucalypt or the pine forests. The pine site was established at 1580 stems/ha after clearing of any vegetation and broadcast burning. Pine stems have since been removed in thinnings. Hence, any differences between soils of the pine and eucalypt sites reflect both the species and the subsequent management practices within the pine stand.

The study site at Nundle State Forest is located on Tertiary basalt giving rise to Kraznozem soils. Topography is flat to gently undulating and drainage is good. The native vegetation forms a tall forest of *E. obliqua* L'Herit and *E. laevopinea* R.T. Bak. with an understorey of *Acacia* spp. and grasses (predominantly *Poa* spp.). The pine stand was established after clearing of the native vegetation and broadcast burning. Trees were planted at 2.4 × 2.4 m spacing with no further treatments. As no fertiliser has been applied and no thinning has been carried out, any soil differences here reflect the combined effects of species and the plantation establishment process.

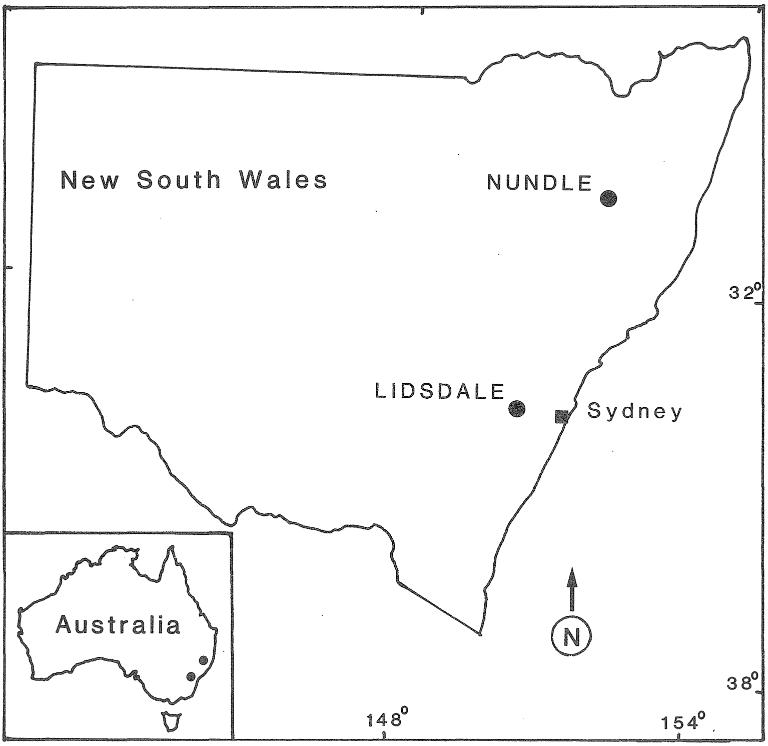

FIG. 1—Location of Nundle and Lidsdale State Forests in New South Wales.

Similar sampling methods were used at both sites. A series of 20 × 20-m plots was established within the *P. radiata* stand and for each plot a paired one, similar in soil type, topography, and aspect, was selected in the adjacent native forest. Twelve paired plots were established in Lidsdale State Forest and 10 paired plots in Nundle State Forest. At Lidsdale, surface soil samples (0–7.5 cm) were taken by bulking 20 random cores (5 cm) per plot. Deeper samples (30–37.5 cm) were taken from a single pit in the centre of the plot. At Nundle, surface soil was sampled from two depths (0–5 cm and 5–10 cm). Twenty random samplings were taken for each plot. Bulk density was estimated from four surface cores (0–5 cm) and two deeper cores (5–10 cm). A circular steel ring of cross-sectional area 0.1 m^2 was used for sampling litter. Each litter sample was sorted into three components, namely woody material, leaf, and other (mainly fine material). The samples of the individual components were weighed then bulked prior to chemical analyses, to provide one sample per component per plot. Soil samples were also taken from Lidsdale for gravimetric moisture content.

Soil samples were air dried and sieved through a 2-mm sieve prior to analysis for total phosphorus and exchangeable calcium, magnesium, potassium, sodium, and aluminium (Lambert 1983). Litter samples were oven dried (70°C) prior to chemical

TABLE 1—Details of the two sites used to study differences in soils properties beneath *Pinus radiata* and adjacent native *Eucalyptus* forest

	Lidsdale	Nundle
Latitude	33° 27' S	31° 30' S
Longitude	150° 04' E	151° 15' E
Elevation (m)	950	1255
Mean annual rainfall (mm)	885	1550
Soil parent material	Devonian shale	Tertiary basalt
Soil rooting depth (cm)	40	110
Pinus radiata		
Age (years)	42	23
Basal area (m²/ha)	18.3	72.3
Mean dominant ht (m)	31	34
Stems/ha	170	785
Eucalyptus spp.		
Age	Not known	Not known
Basal area (m²/ha)	14.8	31.8
Mean dominant ht (m)	11.0	25
Stems/ha	390	533
Species	*E. dives* *E. maculosa*	*E. obliqua* *E. laevopinea* *E. pauciflora* *E. stellulata* *E. radiata*

analysis (Lambert 1983). As the sites were paired (pine *v.* eucalypt), statistical analysis separately for each site was by two-way analysis of variance (Sokal & Rohlf 1969), the main effects being species and location within the forest.

RESULTS

Lidsdale State Forest

Analyses of variance of the data for the chemical analyses of the soils indicated that there were significant differences for most surface soil properties. The soils beneath *P. radiata* at Lidsdale had higher concentrations of organic matter than those beneath *Eucalyptus* (Table 2). In the surface samples, there was a difference of about 0.6% organic matter, and in the deeper sample this difference was about 0.7%. The higher soil organic matter concentrations under pine were reflected in decreased soil bulk density and pH. Total phosphorus in the surface soil under pine was also lower. In the deeper horizon where variability was much greater, total phosphorus concentration was not significantly different. There were no significant differences between the pine and eucalypt soils for exchangeable calcium, magnesium, potassium, and sodium; however, exchangeable aluminium was significantly higher under pine at both depths measured. Moisture content in soil beneath the eucalypts was significantly greater than that in soil beneath pine.

TABLE 2—Mean soil chemical data from two depths beneath *Pinus radiata* and *Eucalyptus* spp. stands at Lidsdale (n = 12)

Depth (cm)	Bulk density (g/c^3)	Soil (%)	pH	N (%)	OM* (%)	C/N	P (ppm)	Exchangeable Ca	Mg	K	Na	Al	Field moisture (%)
										(me %)			
Eucalyptus													
0–7.5													
mean	1.35	81	5.06	0.11	3.87	20.2	130	1.80	1.11	0.37	0.22	0.53	17.4
s.d.	0.11	14	0.28	0.02	0.63		23	1.03	0.44	0.10	0.25	0.50	3.1
30–37.5													
mean	1.62	75	5.02	0.03	0.74	14.1	70	0.22	2.45	0.40	0.24	1.29	15.6
s.d.	0.13	26	0.28	0.001	0.48		14	0.16	1.96	0.17	0.16	1.11	4.4
Pinus radiata													
0–7.5													
mean	1.22	81	4.63	0.09	4.52	28.9	120	1.70	0.99	0.43	0.10	1.81	13.0
s.d.	0.16	11	0.20	0.014	1.05		31	1.12	0.78	0.10	0.06	1.09	4.5
30–37.5													
mean	1.55	59	4.76	0.05	1.43	16.8	105	0.60	1.15	0.41	0.08	2.35	10.3
s.d.	0.18	23	0.25	0.010	0.95		55	1.10	1.50	0.19	0.04	1.44	4.2
L.S.D. ($p = 0.005$)													
0–7.5 0.11	-	0.27	0.01	0.73	6.1	-	-	-	-	-	1.10	3.4	
30–37.5	-	-	-	-	-	-	-	-	-	-	-	1.22	3.6

* Organic matter

Nundle State Forest

At this relatively fertile site, significant soil differences under the two forest types were confined to total nitrogen and organic matter concentrations. Organic matter and nitrogen concentrations were lower in the surface horizons under *P. radiata* than under the eucalypts. For nitrogen, the difference was confined to the top 5 cm soil depth (Table 3), whereas for organic matter there was a significant difference at both sampled depths.

DISCUSSION

In this study, the method used to identify effects of *P. radiata* plantations on soil properties, was to compare soils beneath mature pine with those beneath adjacent native eucalypt forest. The rationale was that changes would occur more rapidly in soil properties under pine than under eucalypt because of greater nutrient demands, and hence differences would be detected after some period. The pine at both locations was planted at a much greater density than that which occurs naturally in the eucalypt forest and the stand productivity was much greater. Thus, in determining impacts on soil, nutrient cycling characteristics of the two stands need to be considered, together with intensity of management. The soils of the studied forests were at extremes of nutritional status for *P. radiata* stands in New South Wales.

Lidsdale State Forest

Tree growth at Lidsdale is retarded, being limited by phosphorus (Humphreys 1964) and the shallow rooting depth available for exploitation by roots (generally 30–40 cm). The stands of both study sites were not treated with fertiliser, although younger *P. radiata* stands in that forest are now routinely treated with phosphatic fertilisers. The above-ground biomass in the pine was more than double that in the eucalypt forest (Lambert 1979) (Table 4) and this difference became more than three times as great when pine thinnings were taken into account.

For this site, the higher productivity of the pine compared with that of the eucalypt has led to increased soil organic matter content, but lower soil nitrogen content. As a result the C/N ratio in the soil beneath the pine was higher than that under the eucalypts. Soil organic matter is considered to be the main cause of decreased bulk density and also of decreased pH, associated with a higher concentration of soil exchangeable aluminium. Soils in this forest are commonly high in exchangeable aluminium and it has been suggested (Humphreys 1964) that the high concentrations recorded could adversely affect phosphorus utilisation by trees in soils low in available phosphorus.

Even though foliage phosphorus concentrations in *P. radiata* (Lambert 1979) at this site (Table 5) were well below the standard critical level (Turner & Lambert 1986b), the stand was economically productive. Foliage analyses showed that nutrient accumulation patterns within the live tissues were similar for both pine and eucalypt with the exceptions that calcium accumulated more in the leaves of the eucalypt species, and aluminium in foliage and in soil (exchangeable) under *P. radiata*. In the leaf (needle) litterfall, phosphorus and aluminium concentrations were much lower in the eucalypt stand than in the pine, and magnesium and potassium were slightly lower under eucalypts while other elements were comparable between species.

TABLE 3—Mean surface soil chemical data from beneath *Pinus radiata* and *Eucalyptus* spp. at Nundle (n = 10)

Depth (cm)	Soil (%)	pH	N (%)	OM* (%)	C/N	P (ppm)	Exchangeable Ca	 Mg	 K	 Na	 Al
							(me %)				
Eucalyptus											
0–5	75	5.81	0.54	20.14	21.4	1490	14.82	5.00	1.93	1.33	0.63
5–10	80	5.76	0.26	12.58	27.8	1425	9.65	3.80	2.21	1.78	0.76
Pinus radiata											
0–5	87	5.88	0.46	16.38	20.5	1495	14.11	4.93	2.58	1.39	0.32
5–10	89	5.83	0.25	10.45	24.0	1520	10.28	4.00	2.36	1.33	0.53
L.S.D. (p = 0.05)											
0–5	7.1	–	0.04	0.31	–	–	–	–	–	–	–
5–10	–	–	–	1.70	–	–	–	–	–	–	–

* Organic matter

TABLE 4—Above-ground organic matter and nitrogen distribution of a *P. radiata* and an *E. dives*/*E. rubida* stand at Lidsdale (Lambert 1979)

Component	*P. radiata*		*E. dives*/*E. rubida*	
	Organic matter (tonnes/ha)	Nitrogen (kg/ha)	Organic matter (tonnes/ha)	Nitrogen (kg/ha)
Tree				
foliage	7.2	84.0	2.2	23.6
branch	23.2	7.0	9.1	14.6
bark	23.6	59.0	18.2	32.7
wood	105.6	46.4	41.9	45.3
Total	159.7	196.4	71.4	116.2
Understorey	0.8	2.6	1.6	13.4
Forest floor				
woody	10.3	64.4	10.9	30.7
leaf	1.9	9.7	0.8	6.0
other	1.7	13.6	1.7	8.9
Total	14.0	87.7	13.5	45.6
Soil (0–7.5 cm)*	33.5	667	31.7	902
Annual turnover				
increment †	9.0	42.5	3.0	15.5
total return to forest floor in litter	3.8	21.5	2.3	10.0
uptake		21.8		6.3
Removals in thinning over 35 years	196	159	0	0
Ecosystem total ‡	404	1113	118	1077

* Estimated only to 7.5 cm depth using data from Table 2

† The difference between increment (requirement) and return to forest floor is redistribution

‡ Includes removals in thinning from the *P. radiata* stand

At this poor site, the changes which have occurred in soil properties under the more productive pines reflect the greater intensity of water and nutrient use. Thus, for example, the moisture content of the soil was significantly less under pine. The slight differences in total phosphorus and exchangeable aluminium and possibly exchangeable potassium and magnesium were most probably due to different nutrient requirements and utilisation by species. The effects are compounded by the limited rooting depth of the soils so that there is higher utilisation within 0–40 cm of the soil surface.

The total nitrogen concentration in the surface soil under pine was lower, by 0.02%, than under *Eucalyptus* and, considering the relatively low level, represents an 18% absolute decline. The difference in total nitrogen concentration deeper in the profile (30–37.5 cm) was not significant. Using the mean soil analyses from Table 2, and converting to kilograms per hectare, the surface soil (0–7.5 cm) beneath the eucalypts had 902 kg N/ha and that beneath the pines had 667 kg N/ha, indicating a difference of 235 kg N/ha. Uptake and accumulation in the above-ground component

TABLE 5 Foliage and leaf litter nutrient concentrations at Lidsdale (Lambert 1979)

Species	Leaf age		Number of samples	N (%)	P	Ca	Mg	K	Na	A1
					(ppm)					
P. radiata	Current	mean	9	1.30	785	1760	1465	4795	65	510
		s.d.		0.24	140	455	395	1420	33	98
	1-year	mean	9	1.21	695	2050	1230	4560	70	600
		s.d.		0.21	120	385	315	895	15	102
	2-year	mean	5	1.19	645	1950	1315	3610	75	680
		s.d.		0.25	85	180	300	430	23	74
	Litter	mean	15	0.48	635	5190	1665	3640	105	875
		s.d.		0.11	145	1570	180	780	40	185
E. dives	Current	mean	5	1.25	720	6125	1910	5030	40	190
		s.d.		0.25	80	1445	265	675	22	33
E. rubida	Current	mean	5	0.92	555	7735	1385	6480	40	140
		s.d.		0.11	55	2115	300	685	6	20
E. dives/*E. rubida*	Mixed litter	mean	12	0.50	250	5915	1235	2035	185	220
		s.d.		0.14	85	2035	265	1065	100	85

of vegetation accounted for part of this, there being 287 kg N/ha in the pines (Table 4) and 175 kg N/ha in the eucalypts. There was, therefore, a deficit of 123 kg N/ha under the pines. It was estimated that harvesting removals were 159 kg N/ha and this would balance the deficit. It is suggested that the lower soil nitrogen content under pines at this site resulted from harvesting rather than from accelerated leaching or other processes.

This study indicated that duplex soils (soils with contrasting texture in different horizons) appear to be utilised intensively only in the surface and are those prone to be affected by nutrient removals as found in other studies (Turner & Kelly 1985). The roots of trees established on soils with a texturally uniform or gradational profile, as in the Factual Key (Northcote 1979) exploit a much greater soil volume; the resultant biocycling can result in a redistribution of nutrients within the soil profile.

The rate of mineralisation of organic matter in litter and soil is directly affected by moisture availability. At a relatively dry site, such as Lidsdale, this is particularly true. The studies of Bell & Gatenby (1969), Smith (1974), and Smith *et al.* (1974) at this site showed that rainfall interception by pines was greater than for eucalypts (18.7% for pines, 10.6% for eucalypts). It has been shown that pines use water more efficiently than eucalypts, in terms of the amount of wood produced (Turner & Lambert 1986c). These results were reflected in the gravimetric soil water contents (Table 2) which, when converted to water potentials (Smith 1974), were −0.051 MPa and −1.41 MPa for the surface soil under eucalypts and pines respectively. That is, there was at the time of sampling, much lower availability of water under the pines than under the eucalypts.

Nundle State Forest

The effect of planting *P. radiata* on the fertile soil at Nundle has been to reduce the organic concentration in the surface soil by almost 4%. This reduction is attributed to initial disturbance during conversion, and also the shading out of the considerable grass understorey normally present beneath the eucalypts.

Nutrient concentrations in the soil were high, the depth of soil available for root growth was relatively large, and any differences were difficult to detect. The stand had not been thinned and hence any potential differences were due to establishment only – that is, there were no nutrient removals due to harvesting.

Relationships with Other Studies

The main question is whether conversion of undisturbed native forest to planted pine significantly affects soil chemical and physical properties. If it does, are the changes likely to seriously affect productivity of the site for forestry purposes, and what specific processes are responsible for the changes which occur under pines? A range of studies has been carried out comparing soils beneath *P. radiata* with soils beneath adjacent vegetation (Table 6). The main consistent effect appears to be a decrease in surface soil nitrogen under pine (Fig. 2) (Turner 1981). This decrease does not appear to result from leaching. More probably, it represents the combined effects of losses incurred during the establishment phase, subsequent redistribution into the vegetation, and harvesting removals. The study at Lidsdale indicates that lower soil nitrogen is due to

TABLE 6—Studies comparing soils beneath *P. radiata* plantations with those of adjacent vegetation

Location	Soil parent material	Reference
Victoria	Sand (low quality)	Hopmans *et al.* (1979)
Victoria	Sand (high quality)	Hopmans *et al.* (1979)
New South Wales	Shale	Present study
Victoria	Quartzite	Feller (1978, 1983)
New Zealand	Pumice	McIntosh (1980)
New South Wales	Granite	Turner & Kelly (1977)
New South Wales	Granite	Turner & Kelly (1977)
Chile	?	Calvo *et al.* (1979a)
Victoria	Basalt	Goldsworthy (1975)
New South Wales	Basalt	Present study

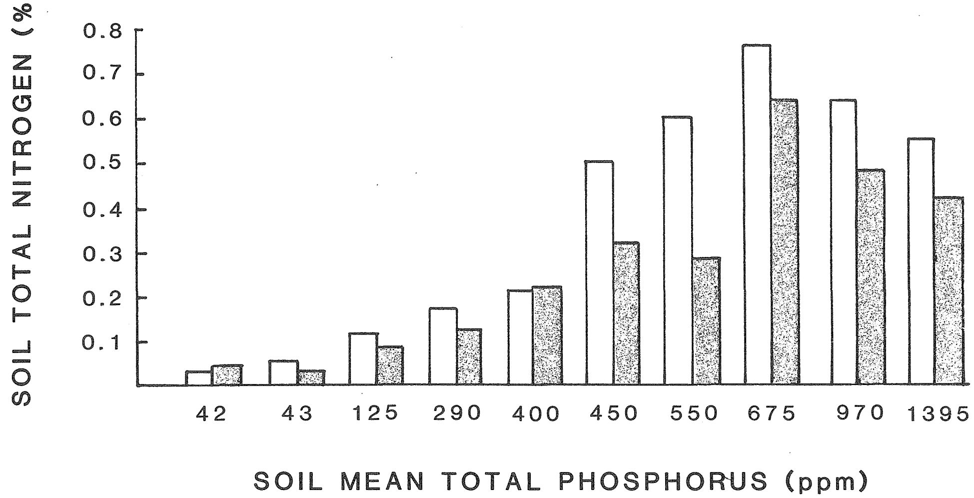

FIG. 2—Concentration of nitrogen in soils of planted pine (▨) and adjacent native vegetation (☐) over a range of soil types with different total phosphorus concentrations. The data were from the following studies from left to right respectively: Hopmans et al. 1979; A. Hatch pers. comm.; Lidsdale (this study); Turner & Kelly 1977; Turner & Kelly 1977; Calvo & Diaz-Fierros 1981; Atkinson 1959; Goldsworthy 1975; McIntosh 1980; Nundle (this study).

greater accumulation of nitrogen in the tree biomass and removal from the site in thinnings. A similar pattern of nitrogen decrease in soil over a period of 19 years was noted by Stangenberger (1968) where *P. radiata* was planted on grassland (that is, the native vegetation was grassland) in California. By 30 years of age, there were higher quantities of nitrogen but soil morphological differences were noted at time of sampling indicating the 30-year site was not comparable. In the 19-year-old stand there was a decrease of 1170 kg N/ha in the top 23 cm; of this, 480 kg/ha could be accounted for in the above-ground vegetation and approximately 250 kg/ha in the below-ground biomass. On this site, which was the only site with previously natural grassland, there was a nitrogen deficit.

A decline in soil nitrogen would be most critical at the lower end of the fertility range, such as for sites with less than 150 ppm soil total phosphorus in the A horizon (Fig. 2). At such sites, phosphorus is likely to be limiting to tree growth and phosphatic fertilisers would be required. Application of phosphate would have the over-all effect of accumulating soil nitrogen from biological fixation (*see* Turner & Lambert 1986a). In that study, increasing quantities of superphosphate were added to a *P. radiata* stand. After 30 years, there was an additional 787 kg N/ha where the treatment was 100 kg P/ha, compared with the untreated plot.

In the present study and those listed in Table 6, the pine stands were not treated with fertiliser and hence trends can be related to soil total phosphorus in the A horizon, used here as an index of soil fertility. The pattern of soil nitrogen flattens out at higher levels of phosphorus (Fig. 2) probably owing to greater quantities of iron-bound and occluded phosphorus in these soils, rather than phosphorus being in organically-related forms (Kelly *et al.* 1983) as in other coniferous species (Turner & Kelly 1977), and it is suggested that part of this pattern may be due to disturbance at time of planting. Other patterns of variation may be related to interactions between fertility and available rooting depth. For forest soils with limited rooting depth, the A horizon will be more subject to depletion than that in a profile with a greater depth available for rooting (Turner & Kelly 1985).

Cation accumulation occurred in the soil surface, and was probably derived from deeper in the soil profile. On poorer sites such as deep sands (Hopmans *et al.* 1979) and at Lidsdale (this study), exchangeable aluminium within the surface soil horizon resulted from release of aluminium from needle litter rich in this element. Such soils are probably more sensitive to change than more fertile soils.

There does not appear to be any specific process, such as podsolisation, which is significantly accelerated under *P. radiata* relative to the adjacent native species. This is probably because most of the studies conducted to date use *Eucalyptus* as a basis for comparison – a genus with high potential for podsolisation (Ellis 1969). Under *Eucalyptus,* the rate of leaching of iron and aluminium from upper horizons is greater than under pine or *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir), indicating a greater potential for podsolisation (Turner & Kelly 1977).

Feller (1978) estimated nutrients in water leached from forest floor beneath pine and eucalypt litter. He reported that the amount of water passing through pine litter was less than through eucalypt and that the concentration of cations in the leachate was lower. As a result, significantly lower concentrations of cations enter the surface soil under pines than eucalypts and this was reflected in available nutrients in the soil. This pattern with lower concentrations of cations under conifers has not been reported in many situations in comparative studies. As the pine and eucalypt sites chosen for Feller's study were not strictly comparable in soil clay content, the apparently aberrant result should be treated with caution. Calvo *et al.* (1979b) compared leachates collected in the rooting zone of *P. radiata* and *Quercus robur* L. Less water was obtained from the

P. radiata and it was 1 pH unit lower. All nutrients and aluminium under pine were similar to the oak or lower, except for nitrogen which was considerably higher. Thus, while differences may be found in soil solutions between species, the net effects on soils need to be considered.

In terms of long-term productivity of forest sites, the two critical elements are nitrogen and phosphorus. Skinner & Attiwill (1981a, b) indicated that previous land use (grassland, native forest, or pine) affected the subsequent productivity, the highest productivity arising from soils carrying pasture. The differences appear to be due to differences in availability of nitrogen and phosphorus via their cycling patterns.

CONCLUSIONS

At a low-fertility site planted in *P. radiata,* the soil had lower pH, total nitrogen, and exchangeable magnesium concentrations but higher organic matter and exchangeable aluminium concentrations than that under adjacent native forest. The *P. radiata* site also had lower soil moisture content. Part of the difference in soil nitrogen content could be accounted for by greater accumulation of nitrogen in the biomass of the more productive *P. radiata.*

At a relatively fertile site, concentrations of soil nitrogen and organic matter were lower under pine than under native forest but other soil properties were not significantly different.

The results of the study are generally consistent with similar studies, showing a decline in soil nitrogen and organic matter content after planting with *P. radiata.* Soils at the lower end of the fertility range may be subject to accelerated nutrient depletion under pine; however, such soils are those most likely to be treated with fertilisers. Application of phosphatic fertilisers to these nutrient-poor sites commonly leads to increased productivity with a substantial increase in nitrogen accretion through natural biological processes.

Phosphorus and cation levels varied and appear to relate to the soil types. Duplex soils appear more prone to nutrient depletion in the surface soil than uniform or gradational soils. This results from more intense exploitation of the surface soil by tree roots in duplex soils owing to physical impediments to deeper root penetration.

There is no evidence for accelerated processes, such as podsolisation, occurring as a result of pine planting.

Further work is needed to study the particular effects which species, density of planting, and specific management practices (e.g., equipment usage, fertiliser applications) have on soil properties and to identify the soil processes which are involved in the changes.

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