INFLUENCE OF SOIL TYPE ON THE NITROGEN AND PHOSPHORUS CONTENT OF RADIATA PINE LITTER

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(Received for publication 2 July 1974; in revised form 18 April 1975)

ABSTRACT

Within plantations of radiata pine in the south-east of South Australia, soil type strongly influences both the weight of litter accumulated on the forest floor and the litter nitrogen and phosphorus contents. Concentrations of nitrogen and phosphorus in litter are smaller, and rates of nutrient turnover are slower on sand podzol soils than on meadow podzols, humus podzols and terra rossa-influenced sands. The weights of nitrogen and phosphorus immobilised in the litter layers on the widely planted sand podzol soils may represent a large proportion of the total weights of these elements in the above-ground components of the plantation stands and could be associated with the problems of maintaining long-term productivity in these plantations.

INTRODUCTION

Relationships between site quality, soil type and the accumulation of litter in *Pinus radiata* (D. Don) plantations growing on sand dune and related soils in the south-east of South Australia have been described by Florence and Lamb (1974). The weight of litter accumulated on the forest floor is influenced by site quality during the earlier years of stand development, but after 30 to 40 years, the weight of litter appears to be related more to soil type than to stand age or site quality. Large accumulations of litter are invariably found on the widely planted sand podzols, and markedly smaller accumulations may be found on some other less common soil types, notably deep terra rossa soils, and some of the soils transitional between sand podzols and terra rossas.

Annual litterfall measurements suggested these differences in litter accumulation are not related to differences in current litter input, but are more likely to be caused by differences between litters as substrates for decomposer organisms, or by differences between decomposer organism populations and stand microclimates at the various sites.

In this paper, the influence of soil type on some litter characteristics is examined in terms of litter nitrogen and phosphorus contents, organic carbon content and litter pH.

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METHODS

The litter sampling sites, productivity ratings and methods of sampling the accumulated litter and litterfall have been described by Florence and Lamb (1974). All stands involved in this study were 30 to 40 years old, and had a productivity rating of SQII or SQ III+. They included four stands growing on sand podzols, four on terra rossa or terra rossa-influenced soils, one on a meadow podzol (= gleyed podzolic) and two on humus podzols or humus podzol-like profiles. This latter category included a soil referred to by Florence and Lamb (1974) as a "Nangwarry-Wandilo" soil. In most respects the profile resembled a Wandilo Sand humus podzol but the A horizon was more typical of a Nangwarry Sand podzol.

Within each stand, the 50 random samples taken to measure litter accumulation were randomly aggregated into four bulked samples. The 15 litterfall samples taken monthly from each of the four stands were similarly aggregated into 4 samples for analysis. Bulked samples were ground, subsampled and analysed for total nitrogen, total phosphorus, organic carbon and pH. Nitrogen and phosphorus contents of the four bulked samples from each site were analysed using a Technicon Auto Analyser (Williams and Twine, 1967). Carbon was analysed on duplicate samples only by the Schollenberger-Allison method, as modified for materials with high organic carbon contents (Metson, 1956). Litter pH was measured on duplicate samples in a 1 : 10 suspension in glass distilled water, allowed to soak overnight.

RESULTS

Chemical Composition of Litter

There were large differences between litters in nitrogen and phosphorus concentrations (Table 1). The sand podzol sites had notably smaller concentrations of litter nitrogen than other sites, in both L and F-layer material. On the sand podzol soils the range in the percent nitrogen of L-layer litter was 0.9 to 1.3% (mean 1.1%), while the range for the terra rossa-influenced soils was 1.3 to 1.7% (mean 1.5%).

The nitrogen concentration of litter at the meadow podzol site was 0.9% and the concentrations at the two humus podzol sites were 1.6 and 1.7%.

There was a similar relationship between soil type and nitrogen concentration in the F-layer litters. At sand podzol sites the range was 2.1 to 2.8% (mean 2.5%) and at the terra rossa sites, 2.7 to 3.3% (mean 3.1%). The nitrogen concentration of litter at the meadow podzol site was 2.3% and the concentrations at the humus podzol sites were 3.1 and 3.5%.

The patterns of phosphorus concentration in litter were similar to those of nitrogen. In the L-layer litter the range in phosphorus concentration was 592 to 788 ppm (mean 694) at sand podzol sites, and 744 to 1022 ppm (mean 869) at all other sites. In the F-layer litter the range in phosphorus concentration at sand podzol sites was 889 to 960 ppm (mean 923). At the seven other sites, all but one stand had an F-layer litter phosphorus concentration in excess of 1000 ppm; thus the concentration in litters from the terra rossa and terra rossa-influenced soils ranged from 920 to 1083 (mean 1014) ppm, the two humus podzol litters had concentrations of 1050 and 1067 ppm and litter from the meadow podzol site had a concentration of 1278 ppm.

Unlike the nitrogen and phosphorus concentration patterns, there was no consistent

TABLE 1—Nutrient and organic carbon concentrations, and pH values of litter layers in 30- to 40-year-old stands of radiata pine growing on different soils. All stands are within the site quality range SQ III to SQ II. Figures in parentheses are standard errors of means

	L-layer litter						F-layer litter					
	Nitrogen (%)		Phosphorus (ppm)		Carbon (%)	pH	Nitrogen (%)		Phosphorus (ppm)		Carbon (%)	pH
SAND PODZOLS												
Mt Burr sand	0.89	(0.03)	712	(49)	48.6	4.96	2.07	(0.14)	889	(33)	39.5	4.65
Mt Burr sand	1.00	(0.02)	592	(23)	48.8	4.96	2.54	(0.16)	951	(36)	37.7	5.14
Mt Burr sand	1.22	(0.04)	788	(22)	48.0	5.26	2.78	(0.18)	960	(48)	40.6	4.94
Nangwarry sand	1.29	(0.04)	683	(21)	50.5	5.35	2.69	(0.15)	893	(60)	41.0	4.98
MEADOW PODZOL/HUMUS PODZOL												
Meadow podzol	0.91	(0.02)	778	(13)	52.7	4.78	2.29	(0.02)	1278	(10)	44.9	4.92
Humus podzol (Wandilo Sand)	1.59	(0.03)	890	(53)	47.6	5.22	3.11	(0.09)	1050	(43)	37.1	4.80
Humus podzol ("Nangwarry-Wandilo Sand")	1.71	(0.07)	869	(9)	49.1	5.12	3.49	(0.10)	1067	(10)	41.0	4.98
DEEP TERRA ROSSA AND TERRA ROSSA-INFLUENCED SANDS												
Terra rossa — sand	1.33	(0.03)	744	(57)	50.0	4.92	2.68	(0.09)	920	(25)	39.2	4.65
Deep terra rossa	1.47	(0.03)	815	(1)	49.2	5.16	3.07	(0.13)	1024	(33)	38.4	4.94
Terra rossa — sand	1.63	(0.02)	1022	(26)	49.3	5.13	3.31	(0.08)	1030	(25)	40.2	5.09
Terra rossa — sand	1.72	(0.05)	967	(8)	49.3	5.16	3.26	(0.12)	1083	(21)	39.9	5.09

relationship between soil type, litter organic carbon concentration and litter pH. Organic carbon concentration ranged from 47.6 to 52.7% in L-layer litter, and from 37.1 to 44.9% in the F-layer litter. The pH of the L-layer litter ranged from 4.78 to 5.35 and that of the F-layer litter from 4.65 to 5.14. At most, but not all sites, the pH of the L-layer litter was greater than that of the F-layer.

Nutrient Accumulation in the Litter Layers

There was a wide range in the weight of nitrogen contained in the litter layers. This varied from 308 kg/ha on one of the humus podzol sites to 679 kg/ha on one of the sand podzol sites (Table 2). Despite these extremes, there is not a strong relationship between the soil type and the weight of nitrogen accumulated in litter. This is because sites with larger weights of accumulated litter generally had smaller litter nitrogen concentrations, and sites with smaller weights of litter generally had the larger litter nitrogen concentrations. Thus 26.5 tonnes/ha of litter at a Mt Burr sand site contained as much nitrogen (505 kg/ha) as 17.2 tonnes/ha of litter at a terra rossa-influenced site (498 kg/ha). Sites with the greatest and least weights of litter nitrogen were sites with particularly wide differences in the weight of litter accumulated.

Similarly, there was a wide range in the weight of phosphorus immobilised in the litter layers (11.5 to 25.6 kg/ha), and again there was no consistent relationship between soil type and weight of phosphorus (Table 2). However, because the range in litter phosphorus concentrations was not as great as that of nitrogen, the sites with smaller weights of litter generally had smaller weights of litter phosphorus. Thus, the greatest weights of litter phosphorus were on the Mt Burr sand podzols and the least on the terra rossa-influenced sands and the humus podzol (Nangwarry-Wandilo) soil.

Nitrogen and Phosphorus in Current Litterfall

Litterfall was collected monthly at four sites. These included stands growing on a Mt Burr sand, a soil transitional between a terra rossa and a Mt Burr sand, a Nangwarry sand, and the humus podzol with a particularly small litter accumulation.

The concentration of nitrogen in litterfall varied widely during the year (Fig. 1). It remained relatively small during the period February to July, and rose to a sharp peak in August. The concentration was again relatively small in September, and rose to a peak in November before declining to a low point in January. This seasonal pattern was essentially similar at each of the four sites. The concentration of nitrogen in the litterfall was greater at the humus podzol and terra rossa-influenced sites than at the sand podzol sites during the period February to June, but from August through to December there was no consistent difference between the sites. In January the sand podzol sites again had smaller concentrations than the other sites.

The phosphorus concentrations in litterfall also show a strong seasonal pattern. They were consistently small between January and July, but increased with subsequent peaks in August and the late spring period generally. The phosphorus concentrations were distinctively smaller at the two sand podzol sites only at the January and February samplings. Thereafter, there was no consistent difference between the sites.

The smaller concentration of nitrogen and phosphorus in the litterfall in stands on sand podzol soils in the early part of the year could reflect a particularly efficient with-

TABLE 2—Weights of nitrogen and phosphorus (kg/ha) contained in the litter layers of 30- to 40-year-old stands of radiata pine growing on different soils. All stands are within the site quality range SQ III to SQ II. Figures in parentheses are standard errors of means.

	NITROGEN						PHOSPHORUS					
	L-layer		F-layer		Total litter		L-layer		F-layer		Total litter	
SAND PODZOLS												
Mt Burr sand	33	(1)	472	(39)	505	(39)	2.6	(0.2)	20.3	(1.2)	22.9	(1.3)
Mt Burr sand	51	(2)	425	(39)	476	(39)	3.0	(0.1)	15.9	(1.2)	18.9	(1.2)
Mt Burr sand	72	(4)	607	(46)	679	(46)	4.7	(0.3)	20.9	(1.9)	25.6	(1.9)
Nangwarry sand	52	(2)	372	(29)	423	(29)	2.8	(0.1)	12.3	(1.1)	15.1	(1.1)
MEADOW PODZOL/HUMUS PODZOL												
Meadow podzol	91	(4)	288	(39)	379	(38)	7.8	(0.4)	16.1	(0.2)	23.9	(2.2)
Humus podzol (Wandilo Sand)	77	(5)	458	(35)	535	(36)	4.3	(0.4)	15.5	(1.3)	19.8	(1.3)
Humus podzol ("Nangwarry-Wandilo Sand")	105	(7)	203	(21)	308	(22)	5.3	(0.3)	6.2	(0.6)	11.5	(0.7)
DEEP TERRA ROSSA AND TERRA ROSSA-INFLUENCED SANDS												
Terra rossa—sand	43	(2)	428	(30)	471	(30)	2.4	(0.2)	14.7	(1.0)	17.1	(1.0)
Deep terra rossa	65	(3)	379	(24)	444	(24)	3.6	(0.2)	12.7	(0.8)	16.3	(0.8)
Terra rossa—sand	79	(4)	346	(22)	425	(22)	4.3	(0.3)	10.8	(0.7)	15.1	(0.7)
Terra rossa—sand	79	(4)	419	(32)	498	(33)	4.4	(0.2)	13.9	(1.0)	18.3	(1.0)

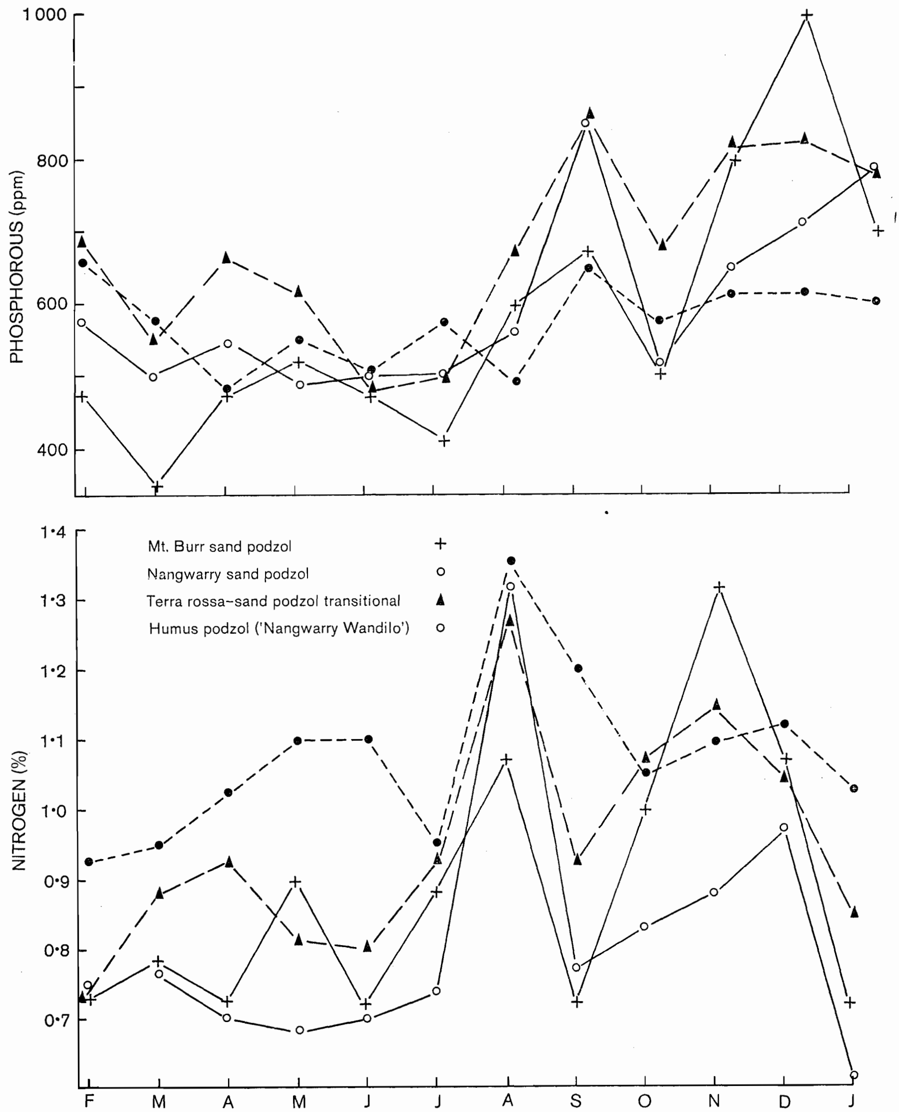

FIG. 1—Monthly variation in nitrogen and phosphorus contents of litterfall in **P. radiata** stands on four sites with different soils.

drawal of nutrients from the older needles prior to abscission to help maintain new shoot growth during a stress period. Florence and Chuong (1974) have already demonstrated that the gradient in foliar nutrient concentrations over the needle age range of one to four years is steeper at sand podzol sites than at terra rossa and terra rossa-influenced sites during the late spring period in these same plantations.

Where the litterfall nutrient data are expressed in terms of weights of nitrogen and phosphorus returned to the forest floor over one year (1969), differences between sites are apparent. The total weight of nitrogen returned to the humus podzol site (29.45 kg/ha) was considerably greater than that at the nearby Nangwarry sand site (17.70), and the weight of nitrogen returned to the terra rossa influenced Mt Burr sand site (31.27 kg/ha) was greater than that on the Mt Burr sand (27.49). Similarly, the weight of phosphorus returned over the year was 1.51 kg/ha on the humus podzol site and 1.33 kg/ha on the Nangwarry sand site; the weight of phosphorus returned to the terra rossa-influenced sand site (2.18 kg/ha) was greater than that on the Mt Burr sand (1.78).

Rate of Organic Matter and Nutrient Turnover

By age 30 to 40 years, an equilibrium may exist between litter accretion and litter decay in radiata pine stands (Florence and Lamb, 1974). If this is so, the ratio of the weight of current litterfall to the weight of litter accumulated on the forest floor may be a useful index for comparing rates of organic matter turnover. Similarly, the ratio of the weights of nitrogen and phosphorus in litterfall to the weights of these elements accumulated on the forest floor may be used to compare the rates at which these elements are moving through the litter layers. These ratios have been calculated for the four stands for which litterfall and litter accumulation data are available (Table 3).

The turnover rates for nitrogen and phosphorus were distinctly smaller on the sand

TABLE 3—Ratio of weights of nitrogen and phosphorus in annual litterfall, to weights of nitrogen and phosphorus accumulated in litter on the forest floor (kg/ha). All four stands are about SQII

	Nangwarry sand (sand podzol)	Mt Burr sand (sand podzol)	Humus podzol ("Nangwarry-Wandilo sand")	Terra rossa influenced Mt Burr sand
Nitrogen				
Fall (1969)	17.70	27.50	29.45	31.30
Accumulation	423.48	679.43	308.46	424.49
Ratio	0.042	0.040	0.095	0.074
Phosphorus				
Fall (1969)	1.33	1.78	1.51	2.18
Accumulation	15.10	25.58	11.54	15.9
Ratio	0.088	0.070	0.131	0.137
Organic matter				
Fall (1969)	3788	3954	3255	4079
(1970)	3789	3361	4125	4195
Accumulation	17 860	27 720	11 830	15 270
Ratio (1969)	0.212	0.143	0.275	0.267
(1970)	0.212	0.121	0.349	0.275

podzol sites. The ratios for nitrogen were 0.040 and 0.042 on the sand podzol sites, and 0.074 and 0.095 respectively in the humus podzol and terra rossa-influenced sites. The ratios for phosphorus were 0.077 and 0.088 on the sand podzol sites, and were considerably smaller than the ratios of 0.131 and 0.137 for the other two sites.

Despite differences in the weights of accumulated nutrients and nutrient inputs, there is apparently a close similarity in the rates at which nutrients are moving through the litter layers of the two sand podzol sites. Similarly, the rates at which nutrients are moving through the litter layers of the humus podzol and terra rossa-influenced sites are comparable. This similarity, however, does not apply to the rates of organic matter turnover; for example, the mean ratio for Nangwarry sand over a two-year period was 0.212 but that for Mt Burr sand was 0.132. These indices of organic matter and nutrient turnover are small, particularly on the sand podzol soils, indicating that decomposition of the pine litter and rates of nutrient release are slow. The indices also suggest the amounts of organic matter and nutrients accumulated on the forest floor are not simply a reflection of differences in annual litter accretion, but are strongly influenced by differences in the rates of litter decomposition and nutrient release.

DISCUSSION

Within the south-east of South Australia, plantation forests of radiata pine contain widely varying amounts of litter, and this litter varies widely in nutrient content, despite similarities in stand age and site quality. The smallest concentrations of litter nitrogen and phosphorus were consistently associated with sand podzol soils which are the principal soil types available for plantation forestry in the region. Despite the smaller concentrations of litter nitrogen and phosphorus at sand podzol sites, some of the largest accumulations of nitrogen and phosphorus by weight were found at these sites, reflecting their particularly slow rates of organic matter decomposition and nutrient release.

There are two possible sources of error in these measurements of litter nitrogen and phosphorus concentration which could influence any conclusions which might be drawn on the turnover of nitrogen and phosphorus in this ecosystem. The first of these is the contamination of the litter layers by mineral soil particles. This is unlikely to cause any significant error because the concentrations of both nitrogen and phosphorus in all these soils are very small (Stephens *et al.,* 1941) and the mineral soil content of the litter layers was low, especially in the upper L-layers. The second factor is the contribution of roots which have grown into the F-layers. No attempt was made to separate these from the general litter layers as an inspection suggested these made a small contribution to the overall litter weight. This relative absence of roots may be due to the long summer dry period in the region. The contribution of those roots which have penetrated the F-layers is unknown but is assumed to be small.

The weights of litter nutrients in the radiata pine forests on the sand dune soils may represent a considerable proportion of the total nitrogen and phosphorus contained in the organic matter of the radiata pine ecosystem. Lewis and Harding (1963) have estimated the above-ground components of a 30-year-old SQ II stand in South Australia may contain 560 kg/ha of nitrogen, and 58 kg/ha of phosphorus (excluding the litter layers). On this basis, the litter layers on the sand podzol soils may hold up to 55% of the nitrogen and 30% of the phosphorus in the aboveground organic matter of the plantations.

In contrast to this, data of Will (1964) indicate that the litter layer of a 35-year-old high quality stand of radiata pine in New Zealand had only 26% of the nitrogen and 14% of the phosphorus contained in the aboveground organic matter of the forest.

The large proportions of nitrogen and phosphorus found in South Australian litter layers, and the slow rates of organic matter decomposition and nutrient release may not, in themselves, be necessarily harmful to the productivity of the present stands. They may, in fact, help conserve ecosystem nutrients by minimising leaching losses from these sandy soils. However, they do represent a temporary immobilisation of a significant proportion of the readily available soil nitrogen and phosphorus within the ecosystem, and could be indicative of inadequacies in the nutrient cycle on sand dune soils and the problems of maintaining forest productivity in the longer term.

The recycling of these litter nutrients in the second rotation after clearfelling and the relationship between large litter accumulations and continued forest productivity on these soils is discussed elsewhere (Florence and Lamb, 1975).

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