ACCUMULATION OF ORGANIC MATTER AND MINERAL NUTRIENTS UNDER A PINUS RADIATA STAND

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ABSTRACT

Accumulation of organic matter and nutrients in the forest floor was examined in a heavily stocked 16-year-old stand of second-rotation **Pinus radiata** D. Don growing on a yellow-brown pumice soil.

The forest floor contained 55 464 kg dry matter/ha and 552 kg N/ha, 36 kg P/ha, 32 kg K/ha, 172 kg Ca/ha, 34 kg Mg/ha, 0.3 kg B/ha, 2.5 kg Zn/ha, 2.5 kg Cu/ha, and 24.1 kg Mn/ha. The relative rate of movement of nutrients through the forest floor was K >> B > Mn > (P, Mg, Ca) > (Zn, Cu) > (N. organic matter).

INTRODUCTION

The litter layer plays a significant part in maintaining the productivity of forest ecosystems. In particular, amounts of litterfall and the rate and nature of its decomposition on the forest floor are important to the efficiency of the overall nutrient cycle (Bray & Gorham 1964).

Previous studies in New Zealand have examined the patterns of litterfall in *P. radiata* stands (Will 1959) and (using mesh bags) the rates of decomposition of litter on the forest floor (Will 1967). Will (1964) estimated, on the assumption that litter takes 3 years to decompose, that under equilibrium conditions the average litter layer under *P. radiata* in the central North Island contains *c.* 13 000 kg dry matter/ha, and 112 kg N/ha, 7 kg P/ha, 13 kg K/ha, and 67 kg Ca/ha. This estimate for dry matter is somewhat less than the equilibrium level of 17 000 kg/ha recorded under unthinned *P. radiata* by Forest & Ovington (1970) at Tumut in New South Wales, and is much at the lower end of the range (11 830 to 27 720 kg/ha) reported by Florence & Lamb (1974) for unthinned 30- to 40-year-old *P. radiata* in South Australia. Likewise, Will's estimates of nitrogen and phosphorus accumulated in the litter layer are considerably below the ranges of 308–679 kg N/ha and 11.5–25.6 kg P/ha reported in litter layers under *P. radiata* in South Australia (Lamb & Florence 1975).

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As part of an investigation into the effects of slash and litter removal on the properties of a second-rotation *P. radiata* site in the central North Island (Ballard & Will 1981), an assessment was made of litter accumulation in the undisturbed forest floor. This report presents these data and examines them in terms of litter layer dynamics.

MATERIALS AND METHODS

Site Description

The site is in Cpt 69 of Kaingaroa State Forest. The first crop of *P. radiata* on the site was drill sown in 1927, left essentially untended for the whole rotation, and clear-felled in 1957–58. After clearfelling the compartment was left to regenerate naturally and where necessary enriched by planting in 1959. In 1963 a plot of 0.16 ha was marked and thinned to roughly 1000 stems/ha. The remaining trees were low pruned, and the thinning and pruning slash was left on the plot. An inner measurement plot of 0.04 ha (20 × 20 m) was established within the plot in 1965. Except for three aerial applications of copper-oxychloride at 2.24 kg/ha between 1968 and 1972 to control *Dothistroma pini* Hulbary infection, the trial area was subject to no further silvicultural treatment before sampling of the forest floor in March 1975. A stem volume assessment just prior to forest floor sampling indicated that the plot contained the equivalent of 535 m^3/ha on 950 stems.

The soil type in the compartment, and in most of Kaingaroa Forest, is Kaingaroa silty sand, a yellow-brown pumice soil formed from rhyolitic ash deposits. A comprehensive description of the soil, geology, topography, and climate of Cpt 69 has been given by Knight & Will (1977). Briefly, the area is *c.* 470. m a.s.l., is almost flat, has a mean annual rainfall of 1413 mm evenly distributed throughout the year, a mean annual temperature of *c.* 10.7°C, 124 days with ground frost, and around 2000 hours of sunshine annually.

Forest Floor Sampling

Twenty, random, square-metre, sampling subplots were established in the inner plot in March 1975. The accumulated litter at each of these subplots was divided into the L layer (litter essentially retaining its original morphology and showing no obvious signs of decomposition), and the F + H layers (all material between the L layer and the surface of the mineral soil). The interface between the two collected layers was fairly sharply defined by the occurrence of a dense mat of fungal hyphae. Any freshly fallen female cones or twigs with a large-end diameter >5 mm were excluded from the L layer collection, but all material in the F + H layers, including cones, bark, and old decomposing wood, was taken. In the laboratory this "woody" material was separated out from "fine" material; at the same time an attempt was also made to separate out any soil inadvertently collected at the somewhat poorly defined interface between the organic and inorganic soil layers. During the field collection the average depth of accumulated litter at each sampling point was obtained by taking two depth readings at each of the four cut faces of the quadrat.

Sample Analysis

All litter samples were oven-dried at 70°C for dry weight determinations, then finely ground prior to element analysis. Nitrogen was determined colorimetrically in the ammonium form after a semi-micro-Kjeldahl digestion procedure using a selenium catalyst. Phosphorus, potassium, calcium, magnesium, boron, zinc, copper, and manganese were determined after dry ashing at 480°C and dissolution of the ash in hydrochloric acid. Phosphorus and boron were determined colorimetrically using the vanadomolybdate and carmine methods respectively, and the cations were determined by atomic absorption spectrophotometry using strontium chloride to suppress interferences.

RESULTS AND DISCUSSION

Litter Accumulation

The accumulated litter layer in the plot (Table 1) is much greater than the 13 000 kg/ha estimated by Will (1964) on the assumption that litter takes 3 years to decompose. It is also considerably greater than the 17 000 kg/ha found under 12-year-old *P. radiata* in New South Wales (Forrest & Ovington 1970), or the highest value of 32 200 kg/ha recorded by Florence & Lamb (1974) in an unthinned, 21-year-old, Site Quality II, *P. radiata* stand in South Australia. The only reported value for *P. radiata* approaching that in Table 1 is the mean value of 42 300 kg/ha recorded by Gadgil & Gadgil (1975) under an undisturbed, unthinned, 22-year-old stand of *P. radiata* regeneration in Kaingaroa Forest. It is of interest that their value is almost identical to that recorded in the current study, with the "woody" material excluded.

TABLE 1—Mean dry weight and nutrient contents (± SE) in litter layers of the forest floor (kg/ha)

	L layer	F + H layer		Total	Ratio L : (F+H fine)
		Fine	Woody		
Dry matter	5813 ± 288	37 979 ± 4811	11 672 ± 2221	55 464	0.153
N	67.5 ± 4.5	414 ± 50	40.6 ± 6.3	522	0.163
P	6.08 ± 0.33	27.9 ± 3.0	2.50 ± 0.40	36.5	0.218
K	13.5 ± 0.67	14.9 ± 3.1	3.56 ± 0.59	32.0	0.906
Ca	26.4 ± 1.3	124 ± 14	21.1 ± 3.6	172	0.213
Mg	5.12 ± 0.25	23.6 ± 2.7	4.81 ± 1.0	33.5	0.217
B	0.060 ± 0.004	0.218 ± 0.030	0.028 ± 0.005	0.31	0.275
Zn	0.37 ± 0.022	1.82 ± 0.20	0.329 ± 0.070	2.52	0.203
Cu	0.40 ± 0.053	2.01 ± 0.22	0.111 ± 0.016	2.52	0.199
Mn	4.57 ± 0.31	18.2 ± 2.1	1.33 ± 0.23	24.1	0.251

The discrepancy between Will's (1964) estimated forest floor accumulation and that observed in this and Gadgil & Gadgil's (1975) studies, could have several explanations. The earlier study was in a first-rotation plantation whereas the latter two studies were in second-crop stands in which some carry-over of woody litter could have been present. Will used litterfall data collected from *P. radiata* stands which, due to mutual suppression and deaths from *Sirex* attack, had a crown cover of only 65–70% (Will 1959). Undoubtedly the litterfall in the fully stocked stand examined in this study would have been much greater than that used by Will. Also, the rate of decomposition of forest floor material under the present stand was probably much slower than the rate assumed by Will because (1) in addition to foliage, on which Will based his decomposition rate, litter in the current plot also contained quite considerable amounts of less decomposable material such as cones, bark, and wood, and (2) conditions under the heavily stocked full-canopied stand were likely to be much less conducive to rapid decomposition than those under the fairly open stand used by Will (Bray & Gorham 1964). The effect of opening up the canopy on decomposition rates is well documented by Wollum & Schubert (1975) who reported that 8 years after a heavy thinning the forest floor under a 51-year-old *Pinus ponderosa* Laws. stand contained 17 700 kg/ha compared to 34 400 kg/ha under the unthinned stand. One other possible contributing factor, which warrants further examination, is that copper levels in the litter are reducing decomposition rates. Copper levels in *P. radiata* foliage normally run at about 4–10 ppm, but copper levels in the litter at this site were 10 times this concentration (Table 2). Tyler (1975) reported reduced mineralisation rates in forest soils in the vicinity of a brass mill; this he attributed to the toxic effect of copper accumulations. The application of copper-oxychloride as a foliar spray is now a common management technique in New Zealand exotic forests for control of *D. pini* infection.

TABLE 2—Mean nutrient concentrations (± SE) in litter layers of the forest floor

Element	L layer	F + H layer	
		Fine	Woody
N (%)	1.150 ± 0.027	1.105 ± 0.030	0.409 ± 0.028
P (%)	0.104 ± 0.001	0.077 ± 0.002	0.025 ± 0.001
K (%)	0.238 ± 0.010	0.037 ± 0.003	0.033 ± 0.002
Ca (%)	0.457 ± 0.011	0.338 ± 0.012	0.199 ± 0.010
Mg (%)	0.088 ± 0.001	0.064 ± 0.001	0.037 ± 0.002
B (ppm)	10.3 ± 0.34	5.9 ± 0.34	2.5 ± 0.12
Zn (ppm)	64 ± 1.4	49 ± 1.4	30 ± 2.2
Cu (ppm)	67 ± 6.0	61 ± 5.5	12 ± 1.4
Mn (ppm)	779 ± 27	506 ± 30	127 ± 7.7

The average depth of the litter layer in the plot was 7.5 cm which, based on casual observation, is much thicker than the litter layer encountered under *P. radiata* subject to the current management practice of thinning once or twice before 16 years of age.

The quantities of nutrient elements accumulated in the litter layer were substantial (Table 1). Based on Madgwick *et al.*'s (1977) estimate of nitrogen ($\cong$390 kg/ha), phosphorus ($\cong$70), potassium ($\cong$440), calcium ($\cong$300), magnesium ($\cong$90), manganese ($\cong$12), and zinc ($\cong$4) in a standing crop of 17-year-old *P. radiata* containing 855 stems/ha, the litter layer holds up to approximately 57% of the nitrogen, 34% of the phosphorus, 7% of the potassium, 36% of the calcium, 27% of the magnesium, 67% of the manganese, and 39% of the zinc in the above-ground organic matter of the forest. For the macro-elements, these percentages are close to those reported for a 16-year-old loblolly pine stand in the south-eastern United States (Wells & Jorgensen 1975). The weights of nitrogen and phosphorus accumulated in the litter layer are very similar to those recorded by Lamb & Florence (1975) despite the marked differences in dry weight.

In contrast to the present study (Table 2), Lamb & Florence (1975) found that the concentrations of both nitrogen and phosphorus increased markedly, going from the L to the F + H layer. Wollum & Schubert (1975) also reported an increase in nutrient concentrations going from less to more decomposed material on the forest floor under *P. ponderosa.* It appears likely that this difference could be associated with the higher rainfall at Kaingaroa Forest which is close to twice that experienced in South Australia and New Mexico. Not only will the higher rainfall enhance leaching of mineralised nutrients from the biologically more active F + H layer but, by keeping the litter layer moist, it will encourage greater rooting activity in this layer. The presence of mycorrhizal roots in the litter layer will tend to prevent increases in nutrient concentrations as they not only increase nutrient uptake, but also act to suppress microbial decomposition of litter (Gadgil & Gadgil 1975).

Relative Rates of Nutrient Turnover

The ratio of the weights of nutrients in current litterfall to weights accumulated on the forest floor has been used (Lamb & Florence 1975) to compare relative rates of nutrient movement through the forest floor. A similar index should be given by the ratio of weights in the L layer to weights in the F + H Layer (Table 1).

Ratios in Table 1 show that the relative rate of movement of the various elements through the forest floor is in the order K >> B > Mn > (P, Mg, Ca) > (Zn, Cu) > (N, organic matter). These trends are also shown in the nutrient concentrations found in the various litter components (Table 2), and give a good indication of the relative efficiency of the cycling of the various elements in this stand.

Provided all other factors are equal, the supply to the tree of elements with the slower turnover rates will be influenced to a greater extent by treatments modifying the litter layer. For instance, treatments such as thinning which enhance decomposition rates will most likely enhance the supply of nitrogen to a much greater extent than potassium, while treatments such as litter raking or windrowing, which remove litter from the site, will probably have a more adverse effect on nitrogen than on potassium supplies.

GENERAL DISCUSSION

Where nutrient budgets have been used to examine or predict the effect of management practices on nutrient reserves of *P. radiata* sites, Will's (1964, 1967) data and estimates have normally been used for the basic information (Knight 1973; Ballard 1976; Webber 1977). The discrepancies between some of Will's estimates and those recorded in the current study illustrate the importance of stand conditions in determining the magnitude and dynamics of biomass components and the attention which needs to be paid to them in extrapolation exercises. The conditions encountered in the second-rotation stand used for the current study – a high level of stocking and a vigorous complete canopy – should have favoured a forest floor accumulation close to the maximum possible for this site.

Accumulation (immobilisation) of nutrients in the forest floor of the magnitude recorded in this study could be detrimental to the productivity of *P. radiata* stands, particularly on sites with low nutrient reserves. It is on such sites that forest managers need to pay careful attention to activities which could influence both the amount of litter accumulation and the losses of litter from the site.

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