PINUS RADIATA FOREST FLOORS: FACTORS AFFECTING ORGANIC MATTER AND NUTRIENT DYNAMICS

M. L. CAREY*, I. R. HUNTER, and I. ANDREW

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

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ABSTRACT

Forest floor organic matter and nutrient contents were quantified in 41 first-rotation and seven second-rotation stands of **Pinus radiata** D. Don (radiata pine) growing in the North Island. Most of the stands were between 18 and 21 years of age.

The forest floors contained an average 20.7 tonnes of organic matter/ha and 258, 18, 32, and 33 kg/ha of nitrogen, phosphorus, potassium, and magnesium, respectively, but there was considerable variation both between and within forests. Ridge and stepwise multiple regression techniques were used to construct models which explained 70, 58, 62, 79, and 82% of this variation. Stocking levels, rainfall, minimum temperature, and foliage calcium levels were the most important variables. The second-rotation sites contained on average twice as much organic matter and nutrients as the first-rotation sites. This was attributed to the fact that no slash burning or clearance had been carried out at the end of the previous rotation.

The forest manager can thus make significant changes to forest floor dynamics through policies on thinning and slash treatment.

INTRODUCTION

Because the rate of litter production generally exceeds the rate of decomposition, large amounts of organic matter containing substantial quantities of nutrients are a feature of the forest floor in many coniferous forests in the Northern and Southern Hemispheres. Radiata pine plantations are no exception and considerable amounts of litter have been found on the forest floor in both New Zealand (Will 1964) and Australia (Florence & Lamb 1974).

Most of the nitrogen and phosphorus in coniferous litter is organically bound. Release for recycling is therefore dependent on the rate of decomposition of organic matter which is determined by (1) microclimate of the forest floor, (2) soil on which the floor develops, and (3) the "resource quality" – that is, the physical and chemical composition of the litter (Heal 1979).

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* Present address: Forest and Wildlife Service, Sidmonton Place, Bray, Co. Wicklow, Republic of Ireland

Much of the published work on litter accumulation has been based on studies carried out in dense natural forests or in manmade plantations, also with high stocking density. Although close initial spacing and delayed commercial thinnings are still the norm in most countries, wide spacing and heavy and early precommercial thinning and pruning are now practised widely in New Zealand (Sutton 1976). The relevance of the results of some of the earlier studies to such situations is, therefore, questionable.

The objectives of this study were to:

(a) Quantify the amounts of organic matter (litter), nitrogen, phosphorus, potassium, and magnesium present in the forest floor beneath a range of radiata pine stands growing in the North Island of New Zealand;

(b) Determine which environmental and silvicultural factors affect the turnover of organic matter and nutrients;

(c) Assess the relevance of the forest floor nutrient pool to tree nutrition;

(d) Draw conclusions regarding the extent to which the state is likely to change as a result of wider spacing and heavy thinning.

METHODS

Site Selection

Forest floor samples were collected from 48 plots (each 0.1 ha) of radiata pine growing in the North Island (Fig. 1). Forty-five of these were in stands aged between 18 and 21 years; the other three were in 16-year-old stands. Most of the plots were permanent sample plots for which comprehensive and reliable data were available on growth patterns, silvicultural management, climate, and soil characteristics, all of which could influence the amounts of litter left on the forest floor. A constraint placed on plot selection was that an increment period of at least 9 years should have elapsed since the previous thinning. Forty-one plots were in first-rotation stands; the other seven were in second-rotation crops which had considerable amounts of slash and litter *in situ* from the previous crop. Measurements from these plots were kept separate from the main group in the subsequent data analysis.

Stand Factors

In the first-rotation plots, the stocking in 1979 varied from 242 stems/ha to 2250 stems/ha, and the basal area (as measured in 1979) from 23.5 m^2/ha to 76.8 m^2/ha. These variations are accounted for by the lack of thinning and the relatively low incidence of tree mortality at two of the sites and early heavy thinnings at others, 35 of which had a stocking less than 730 stems/ha. Thus, although there appeared at first sight to be an ideal opportunity to study the effect of stocking on forest floor dynamics in detail, the paucity of data at the upper end of the scale set limitations.

Site index (estimated mean top height in metres at age 20 years), which was calculated for the plots from the equations given by Burkhart & Tennent (1977), varied between 24 and 36.

Details of stocking, basal area, site index, and elevation of all sites are available from the author.

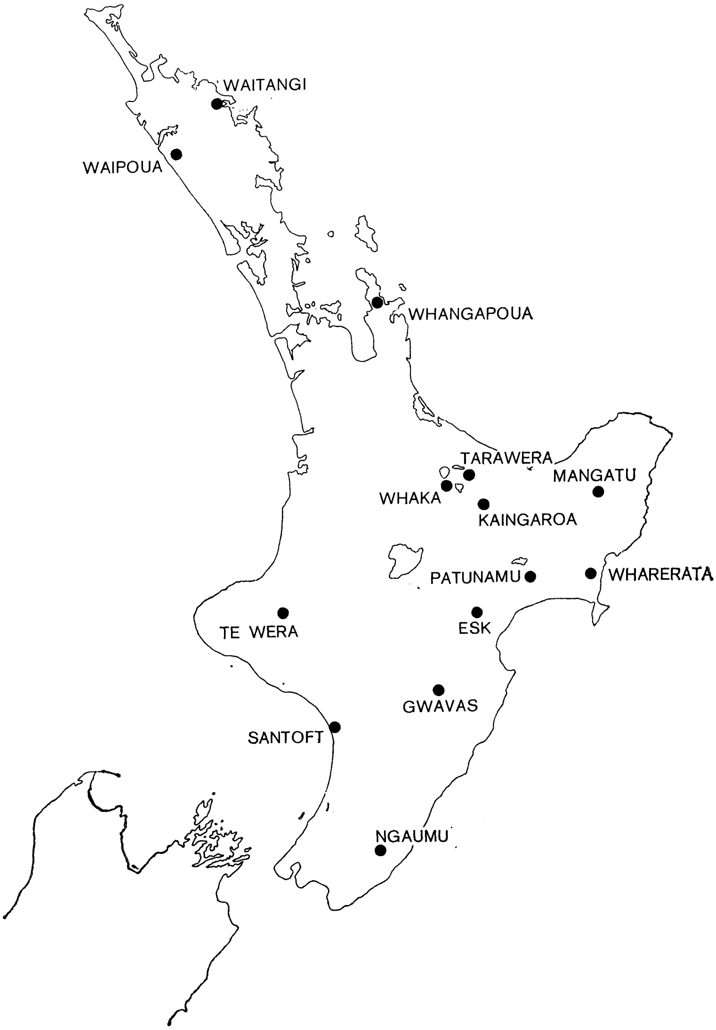

FIG. 1—Location of forest floor sampling sites.

Climatic Factors

The data used were obtained from the published records of the N.Z. Meteorological Service for the years 1968–76, as most of the forests sampled had a meteorological station. Rainfall data tested in the analysis were (i) annual mean, (ii) mean figure for November-April ("summer"), and (iii) mean for May-October ("winter"). Temperature measurements used were (i) mean annual maximum, (ii) mean annual minimum, (iii) mean maximum November-April, (iv) mean minimum November-April, (v) mean maximum May-October, and (vi) mean minimum November-April. No reliable data were available on wind run which could locally influence both litterfall and organic matter dynamics.

Although there was a wide range between sites in the rainfall (921–1921 mm) and mean annual temperature (4.9–11.1°C min. to 15.6–20.4°C max.), there are certain shortcomings in the meteorological data which restrict their usefulness as measures of stand climate in that they refer to forest areas rather than to individual plots within forests. An over-all temperature correction by the adiabatic lapse rate (0.6°C/100 m, N.Z. Meteorological Service pers. comm.) was made for differences in altitude between the meteorological stations and the sampling sites but no correction was made for rainfall.

Soil and Foliage

Soil and foliage analysis data were available for the sites from a Site Productivity Survey (Hunter & Gibson in prep.). The foliage data were confined to nitrogen, phosphorus, potassium, calcium, and magnesium concentrations for the current year's foliage in the upper crown. For the soil samples, the A horizon data were used and the measurements studied included pH, percentage fines (clay plus silt), percentage organic carbon and total nitrogen, Olsen and Bray-extractable phosphorus, and exchangeable calcium, magnesium, and potassium. Methods used for soil and foliage analyses were according to Blakemore *et al.* (1977) and G. Nicholson (unpubl. data) respectively.

Most of the soils fell in the pH range 5 to 6.5. Exceptions were Waitangi (4.5–4.8) and one of the coastal sands at Santoft Forest which was alkaline with a pH of 8.1. Percentage fines varied from 7 to 96. These extremes are found between the coarse calcareous sands at Santoft and the heavy siltstone-derived soils at Ngaumu Forest. The other soil measurements also showed wide variation. Eleven of the soils at the first-rotation sites and all of the soils at the second-rotation sites were derived from volcanic ash. Twenty-nine of the 41 sites had foliage nitrogen levels less than 1.5%, three of which were below 1.2%. Nitrogen levels below 1.5% were considered by Will (1978) to be marginal for growth of radiata pine. Eight sites had phosphorus levels in the marginal to low categories, five sites being equal to or less than 0.12% which is considered low (Will 1978). Three of these were at Whangapoua Forest where responses to applied P have been recorded (Mead & Gadgil 1978). The others were at Santoft and Mangatu Forests.

Forest Floor Sampling

Sampling commenced in October 1979 and was completed in February 1980.

Within each plot 10 sampling points were selected at random. The material collected included the L, F, and H layers as defined by Hoover & Lunt (1952). No attempt was made to separate the three layers. All branch, bark, twig, and root materials greater than 25 mm diameter were excluded unless they were in a highly decomposed state and easily broken between fingers. Living vegetation, bracken stems, and cones (unless they were in a highly decomposed state) were excluded. Dead bracken leaves, which were common on many sites, were included.

To facilitate sampling, a 50 × 50-cm metal frame (7.5 cm deep) was pressed firmly against the forest floor. A sharp knife was used to cut through the organic layers around the edge of the frame and the sample was then carefully removed and placed in a PVC bag. In general the separation of the organic layers from the soil beneath proved easy and the over-all recovery of litter was high while contamination with mineral soil particles appeared to be minimal. Where contamination was thought to be a problem, all of the material was removed and the amount of organic matter determined by loss on ignition.

Laboratory Procedures

Forest floor samples were dried to constant weight at a temperature of 65°C. After the determination of dry weights the samples from each plot were bulked and mixed thoroughly before subsampling for chemical analysis. The subsamples were finely ground and analysed for total nitrogen, phosphorus, potassium, magnesium, and loss on ignition using methods described by G. Nicholson (unpubl. data). Organic matter weights were expressed net (i.e., minus ash content).

Statistical Analysis

The relationships between the quantities of organic matter and nutrients present in the forest floor at the various sites and the climatic, edaphic, crop nutrient, stand density, and productivity variables were explored using ridge and stepwise multiple regression techniques.

RESULTS

Organic Matter and Nutrient Levels

First-rotation sites

The most striking feature of the values for organic matter and nutrient contents and concentrations was the wide variation in organic matter contents between sites. The site with the largest amount – one of the Santoft stands – had 10 times more organic matter on its forest floor than the site with the least amount (at Mangatu Forest) despite being 1 year younger (59.5 *v.* 5.9 tonnes/ha). Such extremes in the data may often be explained by particular characteristics of the sites concerned. The high figure recorded at Santoft forest is from an unthinned stand growing on a light sandy soil whereas the low value at Mangatu relates to a heavily thinned stand growing on a much heavier soil (87 *v.* 9% fines). Large numbers of litter-eating spring-tail insects (Order Collembola) were also a feature of the forest floor in the Mangatu stand. The variation between sites within a forest, although also large, was nevertheless considerably less than that for the over-all sample population. This suggests that regional factors such as climate or geology may play a more important role than localised factors such as soil chemistry or stand management in the turnover of organic matter within the forest floor.

Although organic matter contents generally increased with increasing stocking within forests, there were exceptions where there was either no significant relationship between the two factors or the opposite trend occurred. This was a function of varying amounts of partially decomposed thinning slash in some of the lower density plots as such material increased the amount of organic matter considerably.

The nature and composition of the organic matter also seemed to vary considerably between sites. At Santoft Forest, for instance, the litter layer resembled a mor-like humus in some stands. Mangatu Forest was at the other extreme, with no evidence of H-layer formation.

Variation in nutrient concentrations in the forest floors was generally greater between rather than within forests. Low nitrogen concentrations were associated with low losses on ignition, presumably because of contamination and dilution by mineral soil particles. Phosphorus concentration showed less variation than nitrogen, most values being less than 0.1%. The highest phosphorus levels (0.122 and 0.169% dry matter) occurred at Waitangi Forest and were probably a result of topdressing with superphosphate in 1978. Potassium, calcium, and magnesium concentrations also varied considerably.

The wide variation in forest floor nutrient weights was a reflection of the differences in both organic matter weights and nutrient concentrations. Magnesium showed the greatest variation with a nearly fifteen-fold difference between the minimum (6.9 kg/ha) and maximum (101.7 kg/ha) values. Nitrogen varied from 55 to 660 kg/ha, a twelve-fold difference. Potassium and phosphorus showed much the same degree of variation, there being a seven-fold difference (approximately) for each (9.8–59.5 kg K/ha, 4.7–35.0 kg P/ha). Again, the variation between sites within any one forest was far less than the over-all variation in forest floor nutrient contents.

Second-rotation sites

The seven second-rotation sites, all in Kaingaroa Forest, contained on average double the amount of organic matter found at the first-rotation sites. Approximately 60% of the total amounts present appeared to result from the decomposing slash from the first crop which was felled 18 to 20 years previously. These second-rotation crops were, however, established by natural regeneration and so the results found here are not applicable in situations where slash is burned or windrowed or both, and the new crop established by planting. Nevertheless, the data do provide an indication of the persistence and relatively slow rate of decay of the slash material, and of the potential of the contribution to be made by slash to site organic matter and nutrient reserves. Moisture content analysis at three of the second-rotation sites showed that even in mid-summer the forest floor contained two to three times its dry weight in moisture and thus, besides acting as a mulch, it constitutes a reservoir for soil water.

Although nitrogen and phosphorus concentrations in the forest floor of the second-rotation stands did not differ appreciably from those for the first-rotation sites at Kaingaroa, the values for potassium and magnesium were on average about one-third less. Thus quantities of nitrogen and phosphorus directly reflect the differences in organic matter contents whereas potassium and magnesium contents are the product of varying organic matter weights and nutrient concentrations. The over-all differences between the second-rotation sites are very likely related to the productivity of the first crop and the way in which it was logged. Flinn *et al.* (1979) found that burning of radiata pine logging residues in Australia (south-west Victoria) resulted in a loss of 220 kg N/ha, a figure not unlike that for the difference between the first- and second-rotation sites found here.

Significant Factors

In order to determine which factors significantly affect the forest floor dynamics, the relationship between the organic matter, nitrogen, phosphorus, potassium, and magnesium contents of the first-rotation forest floors and 39 site variables was initially investigated by multiple regression analysis. For this purpose the independent variables were grouped into four categories: (i) stand variables (stocking, basal area, and site index); (ii) climatic variables; (iii) soil variables; and (iv) foliage nutrient concentrations. The resulting correlation matrix was then examined in order to see which factors were most closely related to the forest floor variables. This preliminary screening suggested that site index, stocking, rainfall, soil texture, and foliage calcium and magnesium concentrations were of importance but that the significance of any one differed from one independent variable to another. The correlation matrix also showed that there was a good relationship between the amount of organic matter and the quantities of nitrogen, phosphorus, potassium, and magnesium present in the forest floor, the r values being 0.93, 0.84, 0.73, and 0.88 respectively.

One of the problems that arises in relation to the interpretation of regression analysis of this kind is that there may be a high degree of correlation, or multicollinearity, among some of the independent variables. For instance, annual and summer rainfall are obviously related to each other and their effects on the forest floor dynamics could be indirectly related to the percentage of fines in the soil, assuming the latter is a measure of soil water-holding capacity. The temperature measurements and some of the soil or stand variables could also be inter-related. In such instances the least squares estimates of the regression coefficients may be too large in absolute value, imprecise, and extremely sensitive to small changes in the data. In ordinary least squares regression, estimates of standardised regression coefficients are calculated from the correlation matrix of the explanatory variables. Multicollinearity is indicated by high values of the diagonal elements of the inverse of the correlation matrix; these elements are the variance inflation factors corresponding to each variable: the larger a factor, the greater the contribution of the corresponding variable to the problem of multicollinearity. The consequences of multicollinearity can be reduced by using ridge regression rather than ordinary least squares, to produce estimates of the regression coefficients which are biased, but more precise. This is achieved, in essence, by adding a small constant k (typically less than 0.2), to the diagonal elements of the correlation matrix. There are two problems in using ridge regression: the amount of bias introduced is unknown; and choice of the most appropriate value of the constant, k, may be largely subjective. Bare & Hann (1981) provide a good general description of ridge regression and its use in forest research.

The data sets were therefore analysed using a ridge regression program and the results from this were used in deciding which factors contributed most of the forest floor variation. Variables which were either causing multicollinearity or were not contributing to the regressions were deleted. This resulted in 14 of the original 39 dependent variables remaining for further study. The relationships between these and the forest floor organic matter and nutrient contents were finally tested using stepwise multiple regression. The results of these analyses and the statistical models are given in Table 1.

TABLE 1—Least squares regression estimates

Explanatory variable	Organic matter b	Organic matter (t)	N b	N (t)	P b	P (t)	K b	K (t)	Mg b	Mg (t)	Ca b	Ca (t)
Constant	92.9		1018		46.3		109.1		196		736	
Stems/ha	0.00677	(2.3*)	0.1206	(3.0**)	0.00626	(2.3*)	0.00730	(2.2*)	0.01091	(2.5*)	0.0878	(4.1***)
Site index			–11.04	(2.4*)					–0.891	(1.8)	–4.60	(1.4)
Elevation	0.0646	(2.2*)	–1.064	(2.8**)	–0.0665	(2.3*)	0.0195	(1.6)	–0.156	(3.6***)	–0.876	(4.5***)
Rain,summer	0.0321	(1.4)	0.659	(2.0*)	0.0508	(2.3*)			0.0489	(1.3)	0.496	(2.7**)
Rain,winter	–0.0431	(2.7**)	–0.485	(2.1*)	–0.0571	(3.8**)	–0.0623	(6.8***)	–0.0578	(2.3*)	–0.383	(3.1**)
Temp. min. (year)	–2.94	(1.6)	–59.7	(2.4*)	–2.37	(1.4)			–7.56	(2.7**)	–40.0	(2.9**)
Fines (%)					0.0853	(1.6)			–0.340	(3.6***)		
Ex. Ca	–0.696	(1.8)	–7.10	(1.2)	–0.976	(2.6*)	–2.03	(4.1***)	–1.26	(1.9)		
Ex. Mg							7.08	(4.5***)	8.34	(3.1**)		
Ex. K	1.36	(1.2)	24.8	(1.5)	2.14	(2.0*)	3.90	(3.0**)	2.87	(1.6)		
Foliage N			174	(1.4)	10.2	(1.1)						
Foliage P	74.3	(1.8)	2038	(3.1**)	139	(3.1**)	76.5	(1.8)	165	(1.4*)	914	(3.0**)
Foliage K	–12.3	(1.5)			–9.02	(1.1)	–18.8	(2.2*)				
Foliage Mg	151	(2.6*)			121	(2.2*)	67.7	(1.1)			1300	(2.2*)
Foliage Ca	–207	(4.8***)	–1691	(3.1**)	–138	(3.2**)	–189	(4.0***)	–230	(3.6***)	–1650	(4.3***)
R^2	0.70		0.58		0.62		0.79		0.82		0.74	
Residual Ms	44.9		9560		39.4		57.6		112.9		3122	
Residual df	29		29		27		30		28		31	

* significant at 0.05 level

** significant at 0.01 level

*** significant at 0.001 level

Note: the blank spaces within the table indicate that the variables concerned were excluded from the corresponding regression equation

DISCUSSION

Interpretation of Results

The similarity between the regression results for the five forest floor variables is not surprising because of the close relationship between the forest floor organic matter and nutrient contents. Factors that affect the mineralisation of organic matter affect the turnover of nutrients within the forest floor. However, the importance of any one explanatory variable tends to change between the models. This is a function of differences in the sensitivity of the dependent variables to changes in the explanatory variables. The model for predicting forest floor organic matter is as follows (*see* Table 1):

O.M. content (tonnes/ha) = 92.9 + 0.00677 stems/ha + 0.0646 elevation + 0.0321 summer rainfall – 0.0431 winter rainfall – 2.94 minimum temperature – 0.696 exchangeable Ca + 1.36 exchangeable K + 74.3 foliage P – 12.3 foliage K + 151 foliage Mg – 207 foliage C.

The models for nitrogen, phosphorus, potassium, magnesium, and calcium can be constructed in the same way from the data in Table 1 and used for prediction purposes.

Stocking (stems/ha), elevation, winter rainfall, and foliage calcium and magnesium are related to the amounts of organic matter and nutrients in the forest floor. Foliage calcium is by far the most important variable, its effect being highly significant but negative. High foliage calcium levels are associated with a more rapid turnover of organic matter and nutrients in the forest floor. With a drop in foliage calcium from 0.20% to 0.13%, for instance, which is well within the range of data for the sample plots, there would be a predicted increase of 14.5 tonnes of organic matter in the forest floor. However, until further studies are carried out one cannot be certain whether the higher foliage calcium levels cause or result from increased organic matter decomposition. More than likely they are a cause.

Increasing elevation and winter rainfall are associated with decreasing amounts of organic matter and nutrients in the forest floor. The large amounts of litter found at some of the low elevation coastal sites such as Santoft and Waitangi were probably responsible for the relationship observed in the model. Although increased winter rainfall results in a predicted decrease in litter accumulation, summer rainfall has the opposite effect. The two together suggest that wet summers and dry winters adversely affect the decomposition of radiata pine litter. It could be postulated that the winter rain effect results in part from leaching of nutrients from the forest floor. Although this may hold for potassium, it is unlikely to be so for nitrogen and phosphorus, the major proportions of which are organically bound.

The effects of temperature are generally negative and reached significance for forest floor nitrogen, magnesium, and calcium. From the model for the forest floor nitrogen, it can be estimated that a difference in mean annual minimum temperatures of 4°C, which is well within the range of the data, could result in a difference of 238 kg N/ha in the forest floor, other factors being constant.

The effect of stand density is consistently positive and significant. From the models in Table 1 it can be estimated that a reduction in stand density from, say, 1500 to

380 stems/ha would result in a decrease in organic matter accumulation in the forest floor of 7.58 tonnes/ha ($1500 - 380 \times 0.00677 = 7.58$). The forest floor in a 380 stems/ha stand would contain 135 kg N/ha less, 7 kg P/ha less, 8 kg K/ha less, 13 kg Mg/ha less, and 98 kg Ca/ha less than in a 1500 stems/ha stand. Many silvicultural regimes being practised in New Zealand at present result in stocking being reduced to less than 300 stems/ha by age 10.

Although the percentage fines in the soil initially showed a significant negative correlation with organic matter the effect proved to be non-significant in the final stepwise regression model (Table 1) when combined with stand, climatic, and foliage variables. It could be argued that the percentage fines effect might be confounded with some of the rainfall data. However, a further analysis of the figures, in the absence of the rainfall data, still showed the percentage fines effect to be of no significance for forest floor organic matter, nitrogen, phosphorus, or potassium. The magnesium content of the forest floor did show a highly significant negative correlation with the percentage fines in the soil.

Site index proved to be of statistical significance for forest floor nitrogen content only. The relatioship was negative and suggests that the rate of nitrogen recycling increases with increasing site index. An increase in site index from 24 to 32 would reduce the forest floor nitrogen content by 88 kg/ha, other factors being constant.

The over-all models for the forest floor organic matter, potassium and magnesium, which show R^2 values of 0.70, 0.79, and 0.82 respectively, are reasonably good in that they explain a high percentage of the variation encountered in the study. Those for nitrogen and phosphorus are less satisfactory but nevertheless account for a practically useful amount of the variation. The shortcomings in the models arise because (a) factors other than those considered in the study may affect forest floor dynamics significantly or (b) the methods used to assess the relationship between soil chemistry or climate, for instance, and the forest floor variables may not be relevant. The other major factor contributing to the lack of fit is the variation encountered in the organic matter contents at some sites, which resulted from site disturbance during thinning operations. Nevertheless, the models enable one to predict with a reasonable degree of confidence the amounts of organic matter, nitrogen, phosphorus, potassium, and magnesium likely to be encountered in the forest floor in 18- and 20-year-old stands of radiata pine and how these may be affected by different silvicultural treatments in many situations in the North Island of New Zealand.

General Discussion

Substantial amounts of organic matter and nutrients occur in the forest floor beneath stands of radiata pine growing in the North Island. On average the forest floors in 18- to 20-year-old stands contain 103, 60, 10, and 44% of the amounts of nitrogen, phosphorus, potassium, and magnesium found in the above-ground components of a 22-year-old crop at Kaingaroa by Madgwick *et al.* (1977).

The wide variation encountered in forest floor organic matter and nutrient contents covaries with a number of crop and site variables. The two variables of most significance from a practical point of view are stocking and the percentage of calcium in the foliage. Calcium levels in tree foliage can theoretically be manipulated if so desired by addition of chemicals. Stocking is dictated by the thinning policy in the area concerned. Increased stocking results in larger quantities of organic matter and nutrients on the forest floor; this may be because of either an increase in leaf area index and accelerated litterfall, or reduced rates of organic matter decomposition. Studies by Gadgil & Gadgil (1971, 1975, 1978) have shown that mycorrhizal fungi in association with roots of radiata pine suppress the activity of other micro-organisms and therefore the decompositions of litter. If thinning reduces the number of mycorrhizal fungi then theoretically it should result in an increased rate of litter decomposition. Initial spacing does not appear to be important providing at least 1370 trees/ha are planted at establishment (M. L. Carey, unpubl. data). Stockings less than this, or heavier thinning policies than those encountered in this study, may result in a significant reduction in litter production which in turn will affect the composition of the forest floor. In certain areas, but by no means all, heavy thinning will result in partial if not complete colonisation of the forest floor with secondary vegetation, as in some combined forestry and farming situations. Such factors will obviously affect the forest floor dynamics considerably and the models presented are unlikely to be relevant.

Although the models presented do explain a significant amount of the variation encountered in the forest floors, their inability to explain the actual processes involved must be stressed. Considerable experimentation would be required to identify the actual operating processes in what are complex biochemical mechanisms.

CONCLUSIONS

The obvious question that arises in relation to forest management is whether or not the presence of large quantities of organic matter and nutrients on the forest floor is of any real concern. In general, the relationship between tree nutrient status and the quantity of organic matter and nutrients on the forest floor in this study was poor. The only nutrient to show a negative relationship with the forest floor was in fact foliage potassium. Nitrogen showed no relationship, but increasing foliage phosphorus levels were associated with increasing quantities of organic matter, nitrogen, phosphorus, potassium, and magnesium. The phosphorus relationship was highly significant, suggesting a slow recycling rate through the forest floor for this particular nutrient. The tendency for negative relationships between site index and the forest floor variables, although not strong in statistical terms, nevertheless could be interpreted in two ways: (a) faster growth is a consequence of accelerated turnover of organic matter or nutrients or both in the forest floor, or (b) tree growth and litter decomposition are affected by the same factors but to a different degree.

Despite the generally poor relationship between tree nutrient status and litter accumulation, there are situations in which the immobilisation of nutrients could have serious consequences. The obvious example is Santoft Forest where an unthinned stand with 660 kg N/ha in its forest floor showed definite evidence of nitrogen deficiency. Heavy thinning in this stand could have resulted in a better distribution of nutrients within the ecosystem and reduced the possibility of nitrogen deficiency becoming a problem. Because of the positive effect of stocking on forest floor organic matter and nutrient accumulation, and the poor relationship between the latter and the nutrient contents of the foliage, it could be concluded that in other situations heavy thinning might result in a net loss of nutrients from the system. This can only be considered undesirable. The goal of tree nutrition must be to retain the maximum levels of available nutrients within the ecosystem thereby minimising the need for fertiliser inputs. Where nutrient stress is not a problem, accumulation of organic matter and nutrients in the forest floor may have definite advantages for future rotations.

The results show, therefore, that the forest manager can to a limited degree influence the nutrient dynamics of the forest floor and that in some situations the system can possibly be manipulated to nutritional advantage. The models enable him to predict to what extent different silvicultural policies will change the nutrient balance. However, other factors such as the need for shortened rotations, or a local demand for posts or firewood may well decide the policy on silviculture in any particular area. The data presented give some indication of what these different policies may mean in terms of forest floor dynamics.

The results for the second-rotation sites, although not analysed statistically, strikingly demonstrate the role that the forest manager can play at the end of the rotation in manipulating the organic matter and nutrient dynamics of the forest floor. The decision to burn or remove slash in clearfelled areas has a far greater impact on the forest floor than any other of the variables tested. Where slash is left *in situ,* the organic matter and nutrient pools will very likely be double those at sites where it is burned or removed.

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