CHEMICAL ANALYSIS OF PINE LITTER: AN ALTERNATIVE TO FOLIAGE ANALYSIS?

I. R. HUNTER, G. NICHOLSON, and A. J. THORN
Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

(Received for publication 18 May 1984; revision 14 September 1984)

ABSTRACT

Recently fallen needles were collected from the forest floors of 102 plots of 18- to 20-year-old **Pinus radiata** D. Don in forests in the North Island of New Zealand. At the same time 1-year-old foliage was collected from secondary branchlets. Manganese showed a relatively strong relationship between foliar and litter concentrations; nitrogen, phosphorus, magnesium, boron, copper, and zinc showed a moderate relationship. There were significant differences between forests sampled in the litter : foliage ratios for most nutrients. The method of sampling precluded any attempt to distinguish between the two most likely causes of this difference – forest floor residence time or nutrient cycling. Foliage concentrations were only marginally better correlated with tree growth than litter concentrations.

After further work in calibrating the technique for the specific regions in which it might be used, litter analysis is potentially useful for mature stands (greater than 30 m tall) which are difficult and expensive to sample by other methods.

Keywords: foliage analysis; litter analysis; needle litter; nitrogen; phosphorus; manganese; magnesium; boron; copper; zinc.

INTRODUCTION

In New Zealand there is a large annual programme of collecting *Pinus radiata* foliage for chemical analysis in order to determine which areas of forest require fertiliser. In 1984, 1600 samples were sent to the Forest Research Institute for analysis, the samples originating mainly from forests in the Auckland, Nelson, Canterbury, and Westland regions. Most were analysed for nitrogen and phosphorus; a minority were analysed also for boron, copper, potassium, or magnesium. Twenty percent of the samples came from stands aged less than 6 years, 64% from stands between 6 and 14 years, and 16% from stands aged more than 15 (which would normally be greater than 20 m in height). Of the stands > 15 years, 75% were found to be deficient in one or more elements. In addition to the 1600 samples analysed at the Forest Research Institute an unknown but smaller number of samples were sent to private and company laboratories.

Since stands are sampled approximately every 4–5 years where soils are known to be nutrient deficient, cost-efficiency is important. The first sample from upper crown

secondary branchlets is collected when the stand is 4 years old and approximately 4 m tall, either from the ground or by climbing the tree. In slightly older trees (8 years, 10 m tall) the same type of foliage is collected by pole-mounted cutter or by climbing. Beyond 10 m and up to 30 m tree height a shotgun can be used. For trees up to 20 m, a tight choke gun firing No. 5 shot can bring down a branchlet with each shot. For taller trees the success rate is generally lower and once trees exceed 30 m the method often fails to sever branchlets cleanly with one shot. For trees exceeding 30 m the available methods of foliage sampling are (a) climbing, (b) use of a small-calibre rifle – with the attendant risks of injury to distant forest workers, and (c) sampling from a helicopter. The latter method has been used recently with some success on a management scale. Nitrogen fertilising of marginally deficient stands is the only fertilisation operation directly linked to thinning so the option of collecting foliage from felled trees is not generally available. These tall trees are therefore particularly difficult to sample.

In the early days of foliage sampling in New Zealand forests, the between-tree variation within a few sample plots was used to estimate the desired number of trees to sample within an area to be fertilised (Mead & Will 1976). Recently, however, the same statistic was calculated from within-compartment variation between groups of trees. It was found that for foliar phosphorus the 95% confidence interval of a 25-tree sample was over 0.02% To achieve the more desirable confidence interval of 0.01% the number of trees in a composite sample must be increased to 100 (Hunter, unpubl. data). Based on our experience the cost of sampling foliage in a young 50-ha block (from the ground) to this increased standard would be less than 1% of the cost of the phosphorus fertiliser applied were the block to prove deficient. Using cutters or a shotgun on trees 10 to 20 m tall would cost up to 3% but in trees taller than 30 m climbing could cost 6–8% of the fertiliser cost. Shotgunning would be a cheaper operation provided fewer than four shots were used per tree – a standard difficult to achieve at extreme range. Thus foliage sampling of tall trees is disproportionately expensive.

A small pilot study had been undertaken to identify possible alternative materials for analysis and had indicated that recently fallen litter had greater potential than tree cambium or understorey weeds as a substitute for foliage for diagnostic work (Hunter, unpubl data). Thorough sampling of a compartment would be cheaper using litter than foliage since litter can be collected relatively easily from under most mature stands. Overseas work has also shown that litter sampling could be useful (Lea & Ballard 1982; Miller & Miller 1976; Mahendrappa & Weetman 1973).

A study was therefore undertaken to determine:

- The relationship between nutrient concentrations of recently fallen needles and normally sampled foliage, in forests growing on a range of soil types;
- Whether the relationship varied systematically between sampled forests (Florence & Chuong (1974) and Lamb & Florence (1975) had shown variation by soil type for *P. radiata* in Australia);
- By relating litter and foliage nutrient content to tree growth, which of the two is the better indicator of nutrient status.

METHODS AND MATERIALS

One hundred and two plots of *P. radiata* were selected from amongst the 299 used for a site productivity model (Hunter & Gibson 1984). Selection was carried out to favour plots 18–20 years of age and balanced to give clusters of plots in each forest visited. Tree growth data were available for each plot (Hunter & Gibson 1984). Foliage was collected from secondary branchlets in the upper crown of between five and seven dominant or co-dominant trees per plot by shotgun in early autumn 1979. Recently fallen senescent needles were collected at the same time by sweeping the most recently fallen naturally shed needles lightly from the forest floor with the fingertips. This method was chosen because it was the most cost-effective way such sampling could be conducted in practice. It is also the only practical way to carry out the unplanned sampling initiated by observed foliar chlorosis. Lea & Ballard (1982) used a similar method. Both foliage and litter were analysed for nitrogen, phosphorus, potassium, calcium, magnesium, boron, copper, iron, manganese, and zinc using the methods described by Nicholson (1984).

The relationship between litter concentration and foliage concentration was explored via regression analysis. Since nutrient concentrations in the foliage and litter are sample estimates with an unknown (and possibly substantial) standard error, neither completely satisfies one of the requirements for the independent variable in regression analysis – viz, that it should be measured without error. In the extreme, estimates of regression slope could be very wrong. Regressions were therefore calculated using Bartlett's (1949) method as well as normal least squares, so that this error could be detected.

To test for systematic variation between forests, regressions of the foliage : litter ratio for each nutrient against dummy variables for each forest and the concentration in the foliage were calculated. Tree growth data (site index and recent basal area growth) were available for each plot (Hunter & Gibson 1984). Litter and foliage nutrients were assessed against tree growth by simple correlation.

The predicted relationship between litter and foliage was validated by collecting, in 1979 and 1980, needle litter and foliage from phosphorus-rates trials (described by Hunter & Graham 1982, 1983) and a very nitrogen-deficient site (Hunter & Hoy 1983).

RESULTS

The average nutrient concentration and the range of concentrations for both litter and foliage are shown in Table 1. From the range of foliar concentrations it is apparent that some of the sampled plots were nutritionally deficient for nitrogen and phosphorus, but not for any other nutrient (Will 1978). Results by element and averaged over each forest are given in Appendix 1.

In Table 2 the results of the regression analysis of litter concentration on foliage concentration are shown. Except for copper, there is little difference between the Bartlett's and least squares regression estimates. Three elements (calcium, iron, and potassium) show a very low correlation between foliar and litter concentrations (r^2 below 0.2); potassium is known to leach out of foliage soon after it falls to the forest floor (Will 1967).

TABLE 1—Range and mean of nutrient concentrations in foliage and needle litter

Element	Foliage		Litter		Ratio at the mean
	Mean	Range	Mean	Range	
		(% oven-dry weight)			
N	1.46	0.89–1.97	0.72	0.47–1.11	2.0 : 1
P	0.16	0.07–0.26	0.08	0.02–0.15	2.0 : 1
K	1.17	0.65–1.81	0.32	0.08–0.74	3.8 : 1
Ca	0.17	0.10–0.27	0.60	0.31–1.05	0.3 : 1
Mg	0.15	0.09–0.25	0.14	0.06–0.26	1.1 : 1
		(p.p.m. oven-dry weight)			
B	20	10–36	17	11–32	1.2 : 1
Mn	172	46–591	446	91–1573	0.4 : 1
Zn	44	19–65	31	10–79	1.4 : 1
Fe	52	33–116	90	36–586	0.6 : 1
Cu	5	3–13	6	1–121	0.9 : 1

TABLE 2—Regressions of litter concentration on foliage concentration (oven-dry weights)

Element	Bartlett's method					Least squares	
	a	b	r^2	Significance tests of null hypothesis		a	b
				b = 1	Line = straight		
Boron (p.p.m.)	6.1	0.58	0.41	N	Y	5.9	0.58
Copper (p.p.m.)	-11.8	3.22	0.36	N	?	-26.2	5.89
Manganese (p.p.m.)	-50.2	2.88	0.79	N	Y	-20.7	2.71
Zinc (p.p.m.)	-13.2	1.01	0.41	Y	Y	-15.4	1.06
Iron (p.p.m.)	-3.5	1.78	0.11	Y	Y	-10.4	1.91
Nitrogen (%)	0.15	0.39	0.32	N	Y	0.13	0.41
Phosphorus (%)	-0.02	0.63	0.45	N	Y	-0.01	0.53
Potassium (%)	0.10	0.19	0.07	N	N	0.15	0.15
Calcium (%)	0.31	1.67	0.16	Y	Y	0.30	1.74
Magnesium (%)	0.02	0.75	0.37	N	Y	0.01	0.80

Key N = No.
Y = Yes.
? = Doubtful, probability for rejecting null hypothesis lies between 0.05 and 0.15.

One element, manganese, shows a strong relationship between foliage and litter concentrations (r^2 greater than 0.75). As foliar manganese increases, litter manganese (which is always greater than foliar) increases more rapidly. A group of elements (magnesium, boron, nitrogen, and phosphorus) have a moderate relationship between foliar and litter concentrations and regression coefficients less than 1, implying that litter concentrations increase more slowly than foliar concentrations. Copper probably belongs in this group. Generally (Appendix 1) litter concentrations of copper are less than foliar concentrations but in Kaingaroa, one of the forests where trees are sprayed repeatedly with copper fungicide, they are considerably greater.

A selection of the results of regressing the litter : foliage ratio against foliage concentration and dummy variables for each forest is shown in Table 3. The selection was made to illustrate the main trends observed. Some forests do have statistically significantly different ratios. However, these results cannot be interpreted in the same

TABLE 3—Forests which showed a significant departure from the average litter : foliage ratio

	Element			
	N	P	K	Ca
Forests with lower relative concentrations in litter	Ngaumu Waipoua Woodhill Santoft Gwavas	Ngaumu Santoft Gwavas	 Waipoua Woodhill Santoft Gwavas Te Wera Esk Whangapoua Tangimoana	Glenbervie
Forests with higher relative concentrations in litter	Glenbervie Te Wera	Glenbervie	Mangatu	Santoft Esk Ngaumu Gwavas Waipoua Whangapoua Patunamu
Variation explained (%)	48	36	61	55

way as those of Lamb & Florence (1975) since in our study differences caused by biochemical cycling differences between sites are confounded with changes caused by differing litter residence time on the forest floor. If these data are interpreted using the patterns of variation observed over time by Will (1967) in litter on the forest floor (rapidly decreasing potassium, decreasing phosphorus, and increasing nitrogen) it could be argued that in the forests of (especially) Te Wera, Esk, Tangimoana, and Whangapoua the litter had been on the forest floor longer than in the other forests. On the other hand, if increasing calcium concentration in the litter is viewed as an indicator of the age of the dropped needle, it could be argued that most of the group

of forests with lower litter nitrogen, potassium, and phosphorus concentrations had greater needle retention. This view is strengthened by the parallel behaviour of the manganese ratios – also a good indicator of needle age when dropped. There is no clear relationship to soil texture, however, as found by Florence & Chuong (1974) and Lamb & Florence (1975); for example, the soils of the set with lower litter nitrogen concentrations include recent sands, silt loams, and clays.

The relationship between growth and tissue concentration was explored for nitrogen and phosphorus only since in this study deficiency did not occur in the other nutrients. The relationship for nitrogen, which had by comparison with phosphorus a greater percentage of plots in the deficient range and an over-all mean in the barely sufficient range 1.45% o.d. wt for foliage), was significant at the 5% level but weak. Foliar nitrogen had a log–log correlation of 0.39 against site index and 0.37 against recent basal area increment. Litter nitrogen had a log–log correlation of 0.37 against site index but only 0.09 against basal area increment. On the other hand, the relationship for phosphorus was non-significant for both foliage and litter against both site index and basal area increment although the correlation coefficient was higher for litter (0.19 as against 0.09).

In Fig. 1 and 2 the Bartlett's and least squares regressions for phosphorus and nitrogen in litter and foliage are shown. For phosphorus there is a considerable scatter of verification points around the calculated regressions but no strong visual evidence for a change in regression slope or level. The nitrogen concentrations from the phosphorus-rates trial seem to point to the need for a larger regression coefficient for nitrogen. However, the sample from the very nitrogen-deficient site (WN205) shows a strong correspondence between predicted and actual litter concentrations.

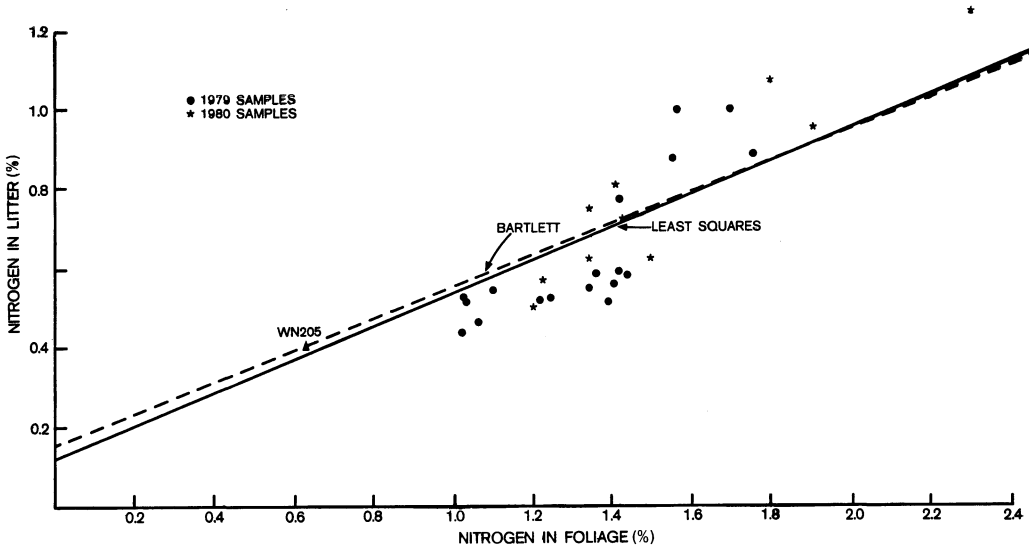

FIG. 1—Independent verification of relationship between foliage and recent litter nitrogen. Regressions from text. Verification data from fertiliser trials described by Hunter & Graham (1982) and from the severely chlorotic site (WN205) referred to by Hunter & Hoy (1983).

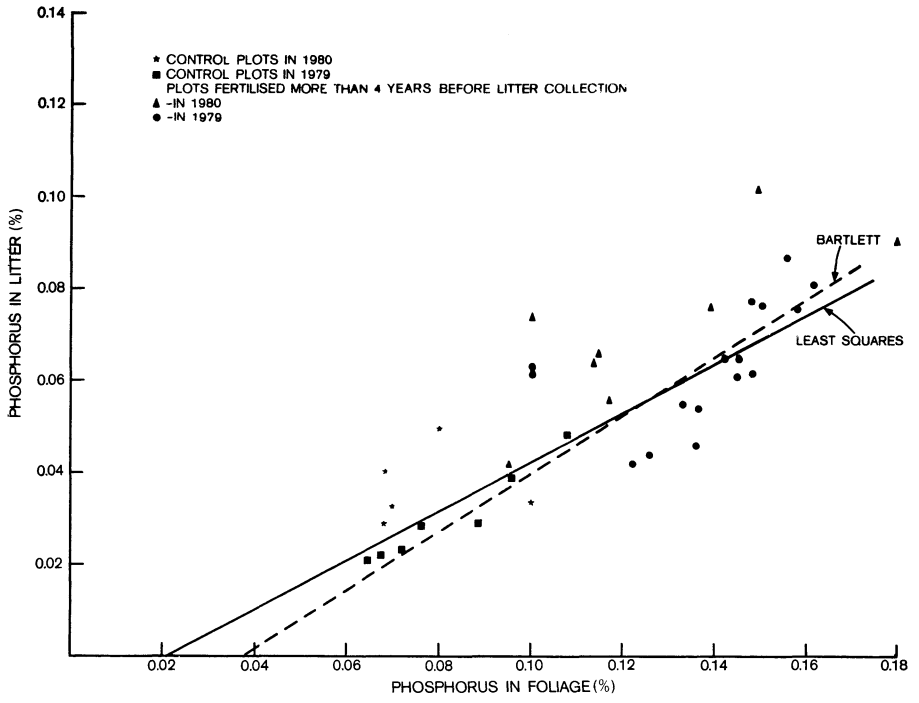

FIG. 2—Independent verification of relationship between foliage and recent litter phosphorus. Regressions from text. Verification data from fertiliser trials described by Hunter & Graham (1982).

DISCUSSION

Only one element (manganese) showed a strong relationship between foliage and litter concentration. For the remaining elements tested, the relationship was either moderate (nitrogen, phosphorus, boron, magnesium, zinc) or weak (potassium, calcium, iron). The relationship between litter and foliage nutrient concentrations was, however, similar to that reported by other workers and in other coniferous species (Mead & Pritchett 1974; Mead & Will 1976; Will 1957, 1967; Edmonds 1980).

Most other studies of this nature (Miller & Miller 1976; Mahendrappa & Weetman 1973; Lea & Ballard 1982) have collected their samples from fertiliser trial sites. Their conclusions about the usefulness of the litter sampling techniques have lacked the general applicability brought to this study by widespread sampling. On the other hand, Mahendrappa & Weetman (1973) showed that the relationship between foliar nitrogen and litter nitrogen could vary between years – an aspect of variability that was not tested directly in this study, although addressed to some extent in the verification exercise and with opposite conclusions. The magnitude of the differences between forests (at 1.5% foliage nitrogen, litter nitrogen could range from 0.6% to 0.9%, and at 0.13% foliage phosphorus from 0.04% to 0.08% litter phsophorus) is such

that in the extreme a mistaken diagnosis could be made. However, as the verification data indicate, on average the diagnosis should be more reliable. Further research is needed to distinguish between the two most likely causes – forest floor residence time and differential nutrient cycling strategies. In the latter, such differences could be handled in the context of a management-scale tissue sampling programme once the soil types or regions to which they apply are more clearly recognised. Forest floor residence time could be more difficult to deal with cheaply if the only practicable solution were to expose litter traps for a known period of time. Some workers have shown that *P. radiata* has peak needle litterfall in the early autumn (Baker 1983) but heavy falls can occur at other times during storms (Will 1959). A change of sampling time, possibly to later in the autumn, should therefore be investigated.

CONCLUSIONS

For the elements for which we are most often asked for a diagnostic report (nitrogen and phosphorus especially) needle litter is sufficiently well correlated to the normally sampled foliage and to tree growth to be used, with caution. as an aid to preliminary nutrient-deficiency diagnoses in very tall trees. With further calibration for the areas in which regular foliage sampling programmes operate, it should prove a useful alternative to foliage sampling of tall trees.

REFERENCES

BAKER, T. G. 1983: Dry matter, nitrogen, and phosphorus content of litterfall and branchfall in **Pinus radiata** and **Eucalyptus** forests. **New Zealand Journal of Forestry Science 13:** 205–21.

BARTLETT, M. S. 1949: Fitting a straight line when both variables are subject to error. **Biometrics 5:** 207–12.

EDMONDS, R. L. 1980: Litter decomposition and nutrient release in Douglas fir, red alder, western hemlock and pacific silver fir ecosystems in W. Washington. **Canadian Journal of Forest Research 10:** 327–37.

FLORENCE, R. G.; CHUONG, P. H. 1974: The influence of soil type on foliar nutrient concentrations in **Pinus radiata** plantations. **Australian Forest Research 6:** 1–8.

HUNTER, I. R.; GIBSON, R. 1984: Predicting **Pinus radiata** site index from environmental variables. **New Zealand Journal of Forestry Science 14:** 53–64.

HUNTER, I. R.; GRAHAM, J. D. 1982: Growth response of phosphorus-deficient **Pinus radiata** to various rates of superphosphate fertiliser. **New Zealand Journal of Forestry Science 12:** 49–62.

——— 1983: Three-year response of **Pinus radiata** to several types and rates of phosphorus fertiliser on soils of contrasting phosphorus retention. **New Zealand Journal of Forestry Science 13:** 229–38.

HUNTER, I. R.; HOY, G. F. 1983: Growth and nutrition of **Pinus radiata** on a recent coastal sand as affected by nitrogen fertiliser. **New Zealand Journal of Forestry Science 13:** 3–13.

LAMB, D.; FLORENCE, R. G. 1975: Influence of soil type on the nitrogen and phosphorus content of radiata pine litter. **New Zealand Journal of Forestry Science 5:** 143–51.

LEA, R.; BALLARD, R. 1982: Relative effectiveness of nutrient concentrations in living foliage and needle fall at predicting response of loblolly pine to N and P fertilisation. **Canadian Journal of Forest Research 12:** 713–17.

MAHENDRAPPA, M. K.; WEETMAN, G. F. 1973: Nitrogen concentration in the current foliage and in fresh litter of fertilised black spruce stands. **Canadian Journal of Forest Research 3:** 333–7.

MEAD, D. J.; PRITCHETT, W. L. 1974: Variation of N, P, K, Ca, Mg, Mn and Al in slash pine foliage. **Communications in Soil Science and Plant Analysis 5(4):** 291–301.

MEAD, D. J.; WILL, G. M. 1976: Seasonal and between-tree variation in the nutrient levels in **Pinus radiata** foliage. **New Zealand Journal of Forestry Science 6:** 3–13.

MILLER, H. G.; MILLER, J. D. 1976: Analysis of needle fall as a means of assessing nitrogen status in pine. **Forestry 49:** 57–61.

NICHOLSON, G. (Comp.) 1984: Methods of soil, plant, and water analysis. **New Zealand Forest Service, FRI Bulletin No. 70.**

WILL, G. M. 1957: Variations in the mineral content of radiata pine needles with age and position in tree crown. **New Zealand Journal of Science and Technology B38:** 669–706.

——— 1959: Nutrient return in litter and rainfall under some exotic conifer stands in New Zealand. **New Zealand Journal of Agricultural Research 2:** 719–34.

——— 1967: Decomposition of **Pinus radiata** litter on the forest floor. Part I: Changes in dry matter and nutrient content. **New Zealand Journal of Science 10(4):** 1030–44.

——— 1978: Nutrient deficiencies in **Pinus radiata** in New Zealand. **New Zealand Journal of Forestry Science 8:** 4–15.

APPENDIX 1

PINUS RADIATA FOLIAGE NUTRIENT CONCENTRATIONS BY ELEMENT AND FOREST AVERAGE

	N	P	K	Ca	Mg	B	Mn	Zn	Fe	Cu
	(% oven-dry weight)				(p.p.m. oven-dry weight)					
Kaingaroa	1.4	0.20	1.2	0.16	0.12	16	260	46	46	6.6
Patunamu	1.6	0.16	1.4	0.16	0.15	22	101	51	44	5.2
Wharerata	1.6	0.15	1.2	0.15	0.13	22	117	44	43	4.9
Mangatu	1.6	0.16	1.4	0.15	0.12	28	130	47	47	3.9
Mohaka	1.5	0.17	1.3	0.18	0.16	10	180	53	53	5.7
Te Wera	1.4	0.13	1.1	0.15	0.13	23	107	36	47	5.9
Gwavas	1.6	0.18	1.3	0.18	0.18	18	128	50	75	6.5
Ngaumu	1.4	0.15	1.4	0.19	0.17	21	260	48	58	6.1
Esk	1.6	0.18	1.3	0.16	0.15	15	135	46	58	4.8
Woodhill	1.3	0.17	1.0	0.17	0.23	21	145	42	56	4.6
Tangimoana	1.3	0.17	1.0	0.15	0.17	19	98	38	68	4.4
Santoft	1.2	0.14	1.0	0.16	0.15	20	77	34	50	3.9
Waitarere	1.2	0.16	0.9	0.18	0.17	19	206	42	71	4.6
Mangawhai	1.3	0.14	0.9	0.21	0.17	18	168	44	65	5.4
Waipoua	1.4	0.16	0.8	0.20	0.19	26	185	52	52	5.0
Whangapoua	1.6	0.10	1.0	0.21	0.16	24	345	46	46	5.4
Glenbervie	1.5	0.17	1.2	0.16	0.15	27	140	47	48	4.1
Waitangi	1.4	0.17	1.1	0.22	0.15	26	240	35	47	5.1

PINUS RADIATA LITTER CONCENTRATIONS BY ELEMENT AND FOREST AVERAGE

	N	P	K	Ca	Mg	B	Mn	Zn	Fe	Cu
	(% oven-dry weight)				(p.p.m. oven-dry weight)					
Kaingaroa	0.78	0.10	0.42	0.47	0.09	13	685	46	62	23.2
Patunamu	0.76	0.09	0.39	0.58	0.13	19	276	45	69	2.6
Wharerata	0.77	0.06	0.33	0.45	0.12	19	271	33	51	2.3
Mangatu	0.80	0.08	0.48	0.53	0.11	22	325	43	53	2.6
Mohaka	0.82	0.09	0.28	0.61	0.13	11	680	34	66	4.0
Te Wera	0.76	0.06	0.30	0.60	0.13	18	325	25	71	3.2
Gwavas	0.72	0.07	0.27	0.74	0.13	14	355	31	166	3.1
Ngaumu	0.59	0.05	0.35	0.70	0.12	17	576	18	125	1.6
Esk	0.82	0.09	0.24	0.62	0.13	13	357	32	72	2.9
Woodhill	0.58	0.07	0.20	0.58	0.22	20	252	26	63	1.8
Tangimoana	0.66	0.08	0.24	0.54	0.19	16	160	25	150	2.1
Waitarere	0.65	0.09	0.38	0.55	0.23	27	441	30	168	1.9
Santoft	0.58	0.06	0.22	0.80	0.17	17	159	17	86	1.7
Mangawhai	0.59	0.06	0.18	0.64	0.17	15	270	19	100	2.6
Waipoua	0.55	0.08	0.11	0.72	0.10	26	329	15	141	2.1
Whangapoua	0.81	0.05	0.31	0.66	0.13	22	956	28	94	2.1
Glenbervie	0.80	0.10	0.39	0.46	0.14	17	290	27	58	2.4
Waitangi	0.82	0.09	0.28	0.61	0.13	11	680	34	66	4.0