NUTRIENT CONTENT AND UPTAKE OF CLOSE-SPACED PINUS RADIATA

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(Received for publication 24 August 1987; revision 3 December 1987)

ABSTRACT

The nutrient content of the above-ground components of a stand of **Pinus radiata** D. Don were estimated between ages 5 and 13 years. Initial spacing was approximately 6900 stems/ha. Total nutrient contents exceeded those of conventional, less densely stocked plantations of comparable age. At age 13 the trees in the stand contained nutrient amounts within 10% of a 29-year-old plantation grown for sawn timber production.

The average rate of accumulation of nutrients into the trees had peaked by age 7 years for most nutrients. The rate of nutrient accumulation depended on the nutrient concerned and the changing pattern of dry matter increment. The rate of accumulation fell most quickly for nitrogen, phosphorus, and potassium for which nutrient concentrations decreased with needle age. The rate was maintained at more stable levels for calcium and manganese which increased in concentration in aging needles.

Keywords: nutrition; nitrogen; phosphorus; potassium; calcium; magnesium; copper; manganese; zinc; boron; **Pinus radiata**.

INTRODUCTION

The use of close-spaced stands grown on short rotations has been suggested as one option for energy farming (Harris *et al.* 1979). However, there is a lack of information on both productivity and nutrient requirements of such plantations in New Zealand. Madgwick & Oliver (1985) described the dry matter content of a young *Pinus radiata* stand between ages 5 and 13 years which had been planted at about 6900 stems/ha. We now report the nutrient concentrations and contents of the same stand. The earlier paper reported that the weight of 1-year-old and total foliage peaked at about age 7, with older foliage forming an increasing percentage of total foliage weight as the stand aged. Live branch weight remained approximately constant and dead branches and stem material increased with time. There was a shift in allocation of increment from needles, branches, and bark to stemwood throughout the 8 years of growth. Maximum mean annual increment of biomass had not been reached by age 13 years when dead trees were included. The accumulation of dry matter and shifts in annual production from nutrient-rich bark and crown components to stemwood with low nutrient concentrations have implications for the maintenance of site quality should such close-spaced stands be used in the future.

New Zealand Journal of Forestry Science 18(1): 65–76 (1988)

MATERIALS AND METHODS

The plantation studied was established between 1970 and 1975 when 50-tree rows of *P. radiata* were planted once or twice a month in the Long Mile area of Rotorua (lat. 38° 10′S, long. 176° 16′E). Nominal spacing was 1 m within and 1.5 m between rows. The plantation was probably affected by spraying of adjacent areas twice a year during the study period with a copper-based fungicide at the rate of 2.08 kg elemental Cu/ha.

Each February from 1980 to 1984 tree diameters were measured and a number of trees sampled to obtain estimates of stand biomass from ages 5 to 13 years. In 1980 the sample was biased towards young age-classes and in 1984 the bias was towards older trees. In each of the other 3 years, two trees were sampled from each age-class present. At the end of the study the sample trees comprised a stratified random sample based on five diameter-classes within each age-class. One tree was sampled from the smallest and the largest diameter-classes and two each from the intermediate small, medium, and intermediate large diameter-classes. Each felled tree was divided into components and weighed. Component weights of individual trees and standard mensurational data were used to estimate stand weights. Details of the sampling design and techniques used have been reported previously (Madgwick & Oliver 1985).

Stemwood, branch, and cone samples were first chipped and then ground to pass a 2-mm-mesh sieve. Stembark and foliage samples were ground to pass 2- and 1-mm-mesh sieves, respectively. Subsamples of ground material were analysed for nutrients using standard Forest Research Institute methods (Nicholson 1984). One subsample was digested with sulphuric acid and hydrogen peroxide in the presence of lithium sulphate and selenium. Nitrogen and phosphorus in this digest were determined by automated colorimetry using indophenol blue and vanadomolybdophosphoric yellow, respectively. Calcium, magnesium, and potassium were determined by atomic absorption spectrophotometry. A second subsample was ashed in a muffle furnace at 480°C for 4 hours followed by digestion with 2N hydrochloric acid and hydroxylamine hydrochloride. Boron was determined by the colorimetric curcumin method, and copper, manganese, and zinc by atomic absorption spectrophotometry.

Analysis of variance was used to examine changes in nutrient concentrations with year of sampling, stem diameter-class, tree age, and sampling location in the stand. The pattern of sampling, dictated by the nature of the plantation, and sampling over a 5-year period resulted in statistical confounding of these sources of variation. The individual factors were examined using one-way analyses of variance. In view of the large number of statistical tests involved, only F ratios exceeding the 1% probability levels are discussed.

Total nutrient contents for each annual estimate of biomass were obtained by multiplying weighted average nutrient concentration by estimated stand weight for eight separate components.

RESULTS AND DISCUSSION

Nutrient Concentrations

Nutrient concentrations in 1-year-old foliage were above "satisfactory" concentrations as given by Will (1985) except for nitrogen (Table 1). Will's data refer to foliage

TABLE 1—Mean nutrient concentrations in needles, branches, and stem material; the significance of variance ratios for one-way analyses of variance for the effects of tree age, year of sampling, position in stand, and stem diameter-class on nutrient concentration; and the residual mean square after the effect of year of sampling was removed (concentrations of N, P, K, Ca, and Mg %; Cu, Mn, Zn, and B ppm)

Component	Element	Mean conc.	Source of variation				Residual mean square
			Tree age	Year	Position	Stem diameter-class	
1-year-needles	N	1.43	ns	*	ns	ns	0.0120
	P	0.18	**	*	**	ns	0.00106
	K	1.09	ns	ns	**	ns	0.0261
	Ca	0.20	ns	ns	ns	ns	0.00235
	Mg	0.12	**	*	**	*	0.000802
	Cu	15	ns	**	ns	ns	73.5
	Mn	205	**	ns	**	ns	4832
	Zn	42	**	*	*	ns	64.0
	B	21	ns	ns	*	ns	19.7
2-year-needles	N	1.28	**	**	**	ns	0.0173
	P	0.14	**	**	**	ns	0.000604
	K	1.11	ns	ns	**	ns	0.0280
	Ca	0.39	ns	ns	ns	ns	0.00965
	Mg	0.10	ns	ns	*	**	0.00202
	Cu	20	**	**	*	ns	204
	Mn	450	**	ns	**	ns	30099
	Zn	40	ns	ns	ns	ns	313
	B	24	**	ns	*	ns	37.6
Live branches	N	0.36	ns	*	ns	**	0.00714
	P	0.07	ns	ns	ns	ns	0.000305
	K	0.56	ns	ns	ns	**	0.0153
	Ca	0.24	ns	*	ns	ns	0.00257
	Mg	0.09	**	**	**	ns	0.000241
	Cu	15	**	**	ns	ns	48.4
	Mn	148	**	**	**	ns	1846
	Zn	30	**	**	ns	ns	47.3
	B	9	ns	ns	ns	ns	2.62
Stemwood	N	0.08	**	**	**	ns	0.000555
	P	0.014	**	**	*	ns	0.0000176
	K	0.12	**	**	**	ns	0.000704
	Ca	0.06	ns	ns	ns	**	0.000238
	Mg	0.022	ns	*	ns	ns	0.0000135
	Cu	1.5	**	**	*	ns	1.55
	Mn	56	**	**	**	ns	255
	Zn	9.3	ns	ns	ns	ns	9.68
	B	2.2	**	**	ns	ns	0.292
Stembark	N	0.34	ns	ns	ns	ns	0.000500
	P	0.044	*	*	ns	ns	0.000126
	K	0.48	ns	ns	ns	ns	0.0162
	Ca	0.39	ns	ns	ns	*	0.0236
	Mg	0.09	ns	ns	ns	*	0.000758
	Cu	12	ns	ns	ns	ns	43.3
	Mn	111	ns	ns	ns	**	1900
	Zn	38	ns	ns	ns	ns	92.1
	B	13	*	*	ns	*	4.03

ns not significant
* significant at 1%
** significant at 0.1%

in the upper crown whereas the data reported here are for the whole crown. Nitrogen concentrations in *P. radiata* foliage have been found to be positively correlated with height in crown (Madgwick *et al.* 1983; Mead 1984) and it is probable that upper crown foliar nitrogen in our stand was above the "satisfactory" level.

Average concentrations of macronutrients in the various components were mostly within the ranges given by Stewart *et al.* (1981) except for potassium and, to a lesser extent, calcium and phosphorus which tended to exceed the maxima reported by those authors in their summary. The exceptions for the woody tissue components resulted from the relatively young age of the trees in our study. Our high average values for potassium were typical of trees growing on the central North Island volcanic plateau (Madgwick *et al.* 1977).

Nutrient concentrations were often related to one or more of the factors: tree age, year of sampling, sampling location within the plantation, and stem diameter-class (Table 1). For example, nitrogen concentrations in 1-year-old needles decreased but potassium, phosphorus, magnesium, and manganese concentrations increased from south-east to north-west across the plantation, with minimum values of calcium in central locations (Fig. 1a). Similar patterns were apparent when average nutrient concentrations were plotted against tree age (Fig. 1b) since tree age also increased across the plantation. Once the apparent effects of sampling location on nutrient concentrations were removed, re-analysis of the data revealed that tree age was no longer significantly related to nutrient concentrations.

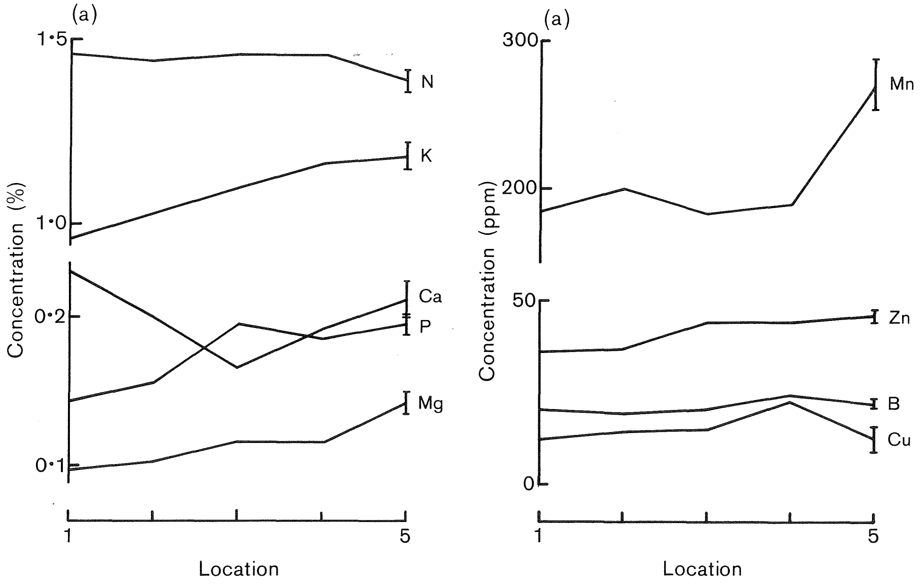

FIG. 1 (a) The relationship between sampling location in the stand and nutrient concentrations in 1-year-old needles. Vertical bars are ± one standard deviation of the mean.

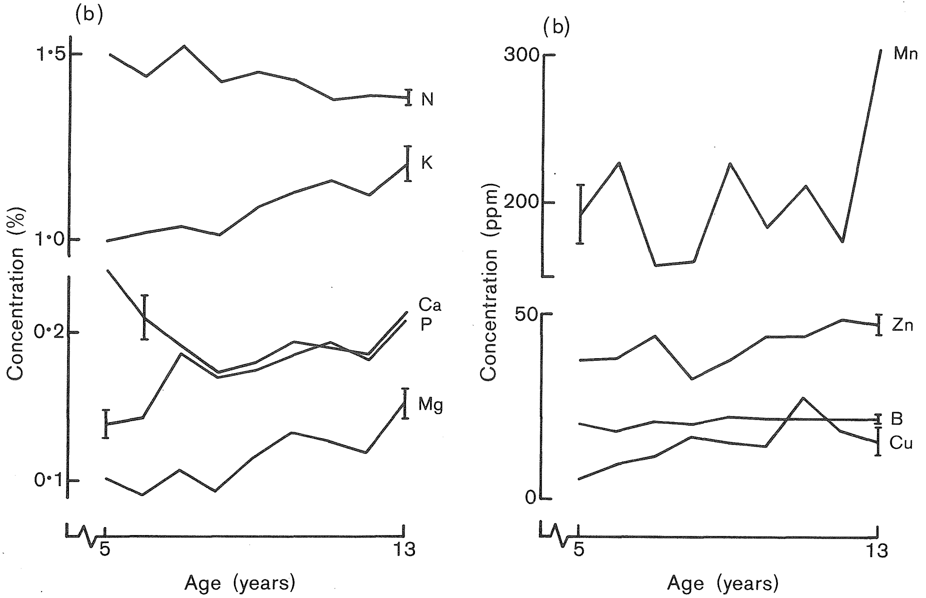

FIG. 1 (b) The relationship between tree age and nutrient concentrations in 1-year-old needles. The vertical bars are ± one standard deviation of the mean.

For live branches, most elemental concentrations increased with tree age (Fig. 2) but again confounding of these effects with sampling location was apparent. Stemwood elemental concentrations (except manganese) decreased with age (Fig. 3). Nutrient concentrations in stembark were mostly unrelated to any of the four factors examined (Table 1). Copper analyses varied with year of sampling because of aerial spraying for disease control (Fig. 4). Peaks in copper concentrations in 1-year-old foliage in Years 2 and 4 were associated with relatively high values of copper in older foliage. To a small extent there was a carry-over effect in foliar copper concentration in 2- and 3-year-old foliage in Year 3 and this was more marked in Year 5. Branch copper concentrations were also high in Year 5. No accurate records of spray applications appear to have been made.

Nutrient concentrations in 1-year-old foliage of *P. radiata* have been reported as decreasing with tree age (Gadgil *et al.* 1984; Lambert 1984) or varying considerably from year to year (Knight *et al.* 1983; Lambert 1986). Average concentrations in woody tissue of *Pinus* spp. are expected to decrease with increasing tree age as individual stems and crowns increase in size (Ovington 1959; Madgwick *et al.* 1977; Gholz *et al.* 1985). It appears likely that there was a nutritional gradient across the site giving rise to apparent changes in nutrient concentrations with tree age. However, statistical confounding of location and tree age effects prevented resolution of the two effects. Only for stemwood was the effect of age on decreasing nutrient concentrations sufficiently great to mask sampling position effects but even here it is possible that concentrations

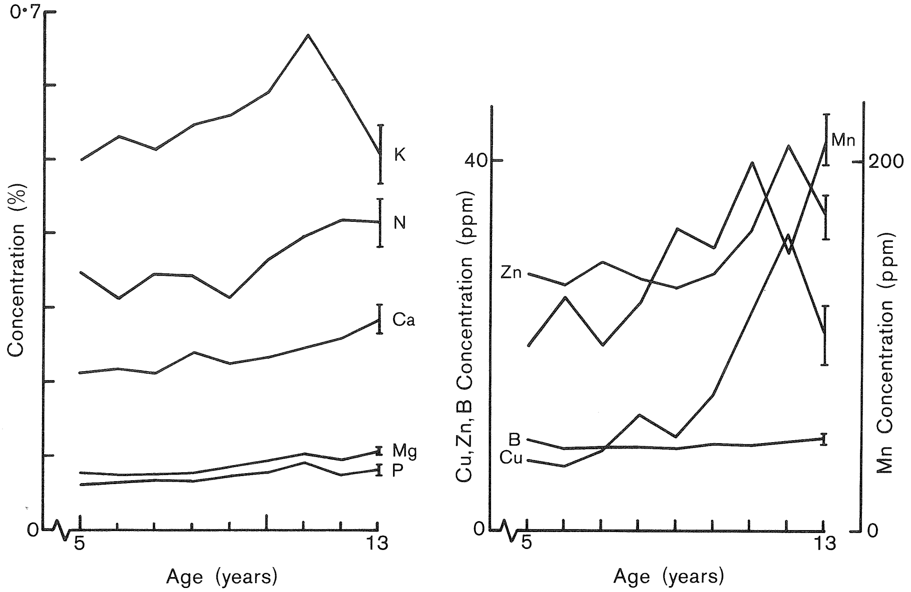

FIG. 2 The relationship between nutrient concentrations in live branches and tree age. The vertical bars are ± one standard deviation of the mean.

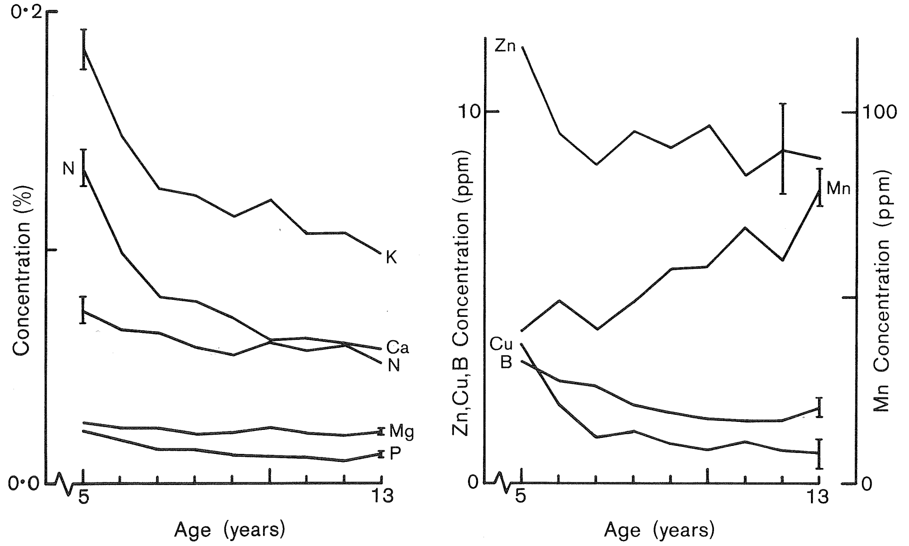

FIG. 3 The relationship between nutrient concentration in stemwood and tree age. The vertical bars are ± one standard deviation of the mean.

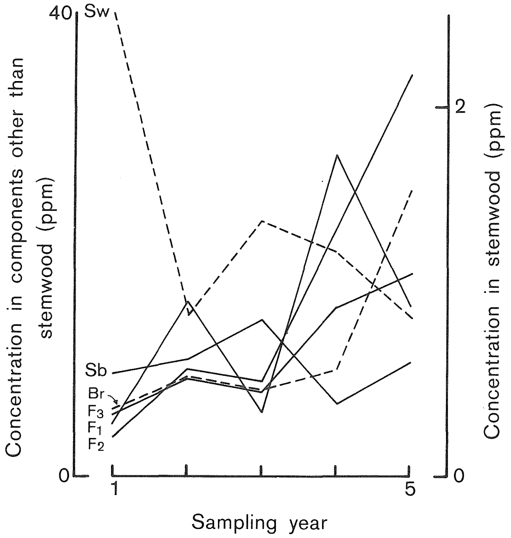

FIG. 4 **The relationship between copper concentrations and year of sampling.**

in the older trees were higher than would have been the case if the site had been strictly uniform. It is probable that the data on total nutrient content of the stand and subsequent estimates of potential nutrient removal in harvesting were biased, with estimates for older stands being larger than might be otherwise expected when compared with the estimates for the younger age-classes.

Nutrient Contents

Total nutrient content of the above-ground components of the trees mostly increased up to age 9 years for each element, and for all except potassium and copper maximum values were found for the 13-year-old trees (Table 2). Total nutrient contents exceeded those previously reported for *P. radiata* plantations of comparable age (Madgwick 1985). The total nutrient contents at age 13 were within 10% of values reported for a sawlog stand at age 29 years by Webber & Madgwick (1983). The high values in the close-spaced stand were associated with higher dry weights of all components except live branches compared with those found in more conventional New Zealand plantations of comparable ages (Madgwick *et al.* 1977; Madgwick & Oliver 1985). Harvesting all material above-ground at age 13 years would have removed approximately the same amount of nutrients as a comparable intensity of harvesting in a conventional plantation at an expected clearfelling age about 30, and would more than double the average annual rate of removal of nutrients from the site.

The total content of nitrogen, phosphorus, potassium, calcium, manganese, and zinc exceeded the amounts predicted by the equations of Madgwick *et al.* (1977) based on the dry matter contents of more widely spaced plantations. For nitrogen, phosphorus, and potassium the degree of over-estimation decreased with stand age and, especially

TABLE 2—The nutrient content of an age series of *P. radiata* stands grown at about 6900 stems/ha

		Stand age (years)								
		5	6	7	8	9	10	11	12	13
Nitrogen (kg/ha)										
Needles	1-year	96	128	154	127	92	66	52	51	49
	2-year	53	64	50	65	72	71	65	53	54
	3-year	5	1	1	6	17	21	30	36	42
Branches	Live	42	38	35	39	42	38	44	56	37
	Dead	6	14	24	26	26	35	36	28	51
Cones		0	3	10	18	18	23	18	18	18
Stems	Wood	60	68	74	80	88	79	97	115	115
	Bark	28	34	36	38	46	42	50	62	66
Total		291	349	384	400	401	374	391	419	434
Phosphorus (kg/ha)										
Needles	1-year	8.5	13.0	17.0	15.2	11.2	8.5	7.7	6.8	7.4
	2-year	5.1	6.9	5.3	7.3	7.9	7.6	8.0	5.7	5.9
	3-year	0.5	0.1	0.1	0.8	2.2	2.4	3.7	3.8	4.7
Branches	Live	7.7	8.9	7.6	8.7	9.7	8.4	10.0	10.4	7.9
	Dead	0.7	1.2	2.1	2.4	2.7	3.3	3.7	3.2	4.2
Cones		0.0	0.6	2.6	4.6	5.5	6.6	4.8	5.1	5.0
Stems	Wood	10.7	13.0	12.9	14.5	15.7	14.8	17.2	16.6	23.4
	Bark	4.0	4.8	4.1	4.7	6.1	5.2	6.4	7.8	8.1
Total		37.2	48.5	51.7	58.2	61.0	56.8	61.5	59.4	66.6
Potassium (kg/ha)										
Needles	1-year	61	93	111	88	71	49	44	43	43
	2-year	52	58	45	59	65	59	56	44	41
	3-year	5	1	1	8	18	19	26	35	40
Branches	Live	61	69	63	67	79	65	79	78	56
	Dead	4	12	15	16	12	21	18	20	18
Cones		0	3	7	11	13	16	11	12	13
Stems	Wood	86	107	109	125	140	133	159	181	202
	Bark	36	51	47	48	73	56	77	93	92
Total		306	394	398	423	471	420	471	506	504
Calcium (kg/ha)										
Needles	1-year	13.5	20.4	20.2	15.8	12.4	8.6	7.0	7.4	7.5
	2-year	22.8	25.7	16.7	21.1	20.3	19.3	15.1	14.1	12.7
	3-year	3.0	0.5	0.4	3.5	7.3	8.4	11.1	13.4	14.4
Branches	Live	27.1	29.5	24.6	29.4	33.2	31.3	30.5	37.8	31.5
	Dead	6.8	18.5	31.7	38.1	36.8	40.5	46.3	30.4	55.7
Cones		0.0	0.1	0.4	0.6	0.9	0.7	0.9	1.4	1.1
Stems	Wood	33.7	42.6	48.9	55.0	58.0	69.7	80.5	96.2	109.8
	Bark	25.9	29.5	40.5	36.8	41.1	50.3	64.9	62.3	73.5
Total		132.8	166.8	183.4	200.3	210.0	228.8	256.3	263.0	306.2
Magnesium (kg/ha)										
Needles	1-year	6.0	8.0	9.9	8.0	7.0	6.0	4.3	4.3	4.6
	2-year	5.9	4.1	3.4	3.5	5.4	4.8	4.3	3.5	3.6
	3-year	0.7	0.1	0.1	0.5	1.4	1.5	2.9	2.5	2.4
Branches	Live	9.3	9.9	8.6	9.4	12.7	11.3	11.8	12.8	10.0
	Dead	2.0	4.3	7.4	7.4	7.8	9.4	10.1	7.3	11.4

TABLE 2—cont.

		Stand age (years)								
		5	6	7	8	9	10	11	12	13
Cones		0.0	0.3	1.0	1.7	2.4	2.8	2.2	3.0	2.6
Stems	Wood	12.6	16.4	20.5	21.1	26.1	29.9	31.0	33.3	42.7
	Bark	5.4	7.1	8.5	8.0	12.1	10.6	12.3	15.1	18.6
Total		41.9	50.2	59.4	59.6	74.9	76.3	78.9	81.8	95.9
Copper (kg/ha)										
Needles	1-year	0.031	0.098	0.105	0.171	0.090	0.075	0.087	0.078	0.054
	2-year	0.021	0.041	0.033	0.086	0.077	0.093	0.115	0.215	0.118
	3-year	0.003	0.001	0.001	0.009	0.019	0.031	0.057	0.077	0.052
Branches	Live	0.087	0.108	0.080	0.180	0.121	0.183	0.276	0.426	0.201
	Dead	0.114	0.163	0.194	0.343	0.272	0.282	0.279	0.213	0.428
Cones		0.000	0.003	0.009	0.019	0.027	0.027	0.027	0.033	0.027
Stems	Wood	0.158	0.146	0.109	0.146	0.139	0.134	0.173	0.172	0.184
	Bark	0.079	0.111	0.108	0.171	0.154	0.141	0.120	0.257	0.211
Total		0.493	0.671	0.639	1.125	0.899	0.966	1.134	1.471	1.275
Manganese (kg/ha)										
Needles	1-year	1.19	2.31	1.69	1.43	1.72	0.81	0.79	0.67	1.06
	2-year	1.76	2.68	1.11	2.17	3.15	1.80	2.47	1.78	2.67
	3-year	0.22	0.05	0.02	0.27	0.85	0.77	1.69	1.55	3.29
Branches	Live	1.31	1.87	1.03	1.50	2.37	1.74	2.47	2.14	2.70
	Dead	0.27	1.03	1.28	1.69	1.89	1.85	2.01	1.35	2.77
Cones		0.00	0.01	0.03	0.05	0.08	0.05	0.07	0.07	0.07
Stems	Wood	1.89	3.32	3.16	4.73	7.11	6.46	10.66	9.73	16.43
	Bark	0.57	0.91	0.79	0.94	1.61	1.19	1.72	1.54	2.54
Total		7.21	12.19	9.11	12.79	18.79	14.68	21.87	18.84	31.54
Zinc (kg/ha)										
Needles	1-year	0.23	0.33	0.46	0.30	0.25	0.19	0.18	0.18	0.15
	2-year	0.24	0.18	0.20	0.14	0.18	0.16	0.20	0.15	0.13
	3-year	0.03	0.00	0.00	0.03	0.04	0.06	0.11	0.11	0.10
Branches	Live	0.35	0.34	0.36	0.36	0.36	0.34	0.38	0.62	0.38
	Dead	0.10	0.21	0.43	0.35	0.34	0.52	0.52	0.46	0.88
Cones		0.00	0.01	0.04	0.06	0.10	0.13	0.09	0.10	0.11
Stems	Wood	0.58	0.67	0.77	1.01	1.13	1.11	1.29	1.45	1.59
	Bark	0.25	0.32	0.42	0.42	0.51	0.47	0.55	0.73	0.74
Total		1.78	2.07	2.70	2.69	2.91	2.98	3.33	3.81	4.08
Boron (kg/ha)										
Needles	1-year	0.124	0.162	0.217	0.159	0.157	0.112	0.083	0.096	0.077
	2-year	0.137	0.114	0.093	0.120	0.176	0.115	0.109	0.100	0.101
	3-year	0.013	0.002	0.002	0.013	0.048	0.039	0.056	0.077	0.084
Branches	Live	0.125	0.121	0.096	0.105	0.128	0.108	0.102	0.141	0.102
	Dead	0.024	0.053	0.089	0.108	0.101	0.120	0.119	0.092	0.166
Cones		0.000	0.004	0.015	0.021	0.031	0.035	0.028	0.029	0.039
Stems	Wood	0.168	0.191	0.206	0.213	0.229	0.214	0.252	0.283	0.431
	Bark	0.096	0.127	0.137	0.135	0.181	0.154	0.189	0.228	0.231
Total		0.687	0.774	0.855	0.874	1.051	0.897	0.938	1.046	1.231

for the older ages, measured values were within one standard deviation of expected amounts. Calcium contents ranged from 34% to 48% above and for magnesium 16% to 3% below expectation. Manganese and zinc contents exceeded expectation especially at older ages. The younger average age of foliage and woody tissue in the close-spaced plantation would be expected to give high average concentrations particularly of nitrogen, phosphorus, and potassium, resulting in higher total nutrient contents than in wider-spaced older plantations containing comparable total biomass.

Rate of Nutrient Accumulation

Dividing total nutrient content by plantation age gave a measure of mean annual increment of nutrients into the stand (Table 3). For macronutrients, zinc, and boron the maximum mean annual increments occurred around age 6 years, indicating that the maximum rate of nutrient accumulation in the trees occurred early in the life of the stand. An estimate of gross nutrient uptake was obtained by adding the increment of nutrient content of wood and bark to the weight of nutrients in 1-year-old foliage and any increase in the total nutrient content of older needles after allowing for needle fall. Such estimates suggested that the annual nutrient uptake continued to be considerable throughout the life of the stand (Table 4). The additional increment of nutrient in woody tissue was relatively small after the first 6 years and the gross uptake of nutrients was then dominated by the amount needed for the new flush of foliage. The decrease in needle production with stand age reduced the annual gross uptake of nutrients such as nitrogen, phosphorus, and potassium, with highest concentrations in new tissue. Increased needle longevity combined with rising concentrations of nutrients with tissue age resulted in more sustained rates of gross uptake of calcium and manganese. Gross uptake of zinc and boron remained more or less uniform over time. We did not measure the amounts of nutrients recycled within the tree but the occurrence of needle fall in the summer months (Will 1959; Frederick *et al.* 1985), when foliage growth is active (Madgwick 1983), suggests that this may be a relatively well-developed way of conserving mobile nutrients in *P. radiata*. The withdrawal of nutrients from needles prior to needle fall (P. N. Beets, pers. comm.) indicates that our calculations of gross uptake of mobile nutrients were over-estimates.

TABLE 3—Mean annual incorporation of nutrients (kg/ha) in the above-ground components of close-spaced *P. radiata* over the life of a plantation

	Stand age (years)								
	5	6	7	8	9	10	11	12	13
Nitrogen	58	58	55	50	45	37	36	35	33
Phosphorus	7.4	8.1	7.4	7.3	6.8	5.7	5.6	4.9	5.1
Potassium	61	66	57	53	52	42	43	42	39
Calcium	26.6	27.8	26.2	25.0	23.3	22.9	23.3	21.9	23.6
Magnesium	8.4	8.4	8.5	7.4	8.3	7.6	7.2	6.8	7.4
Copper	0.099	0.112	0.091	0.141	0.100	0.097	0.103	0.123	0.098
Manganese	1.44	2.03	1.30	1.60	2.09	1.47	1.99	1.57	2.43
Zinc	0.36	0.35	0.39	0.34	0.32	0.30	0.30	0.32	0.31
Boron	0.137	0.129	0.122	0.109	0.117	0.090	0.085	0.087	0.095

TABLE 4—Estimated gross annual uptake of nutrients (kg/ha) in the above-ground components of close-spaced *P. radiata* (based on the increment in woody tissue and the nutrient content in 1-year-old needles and the increase in nutrient content of older foliage after litter fall was accounted for)

	Stand age (years)							
	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13
Nitrogen	147	177	151	110	63	80	88	63
Phosphorus	18.4	17.8	20.8	16.0	7.1	11.8	7.8	12.9
Potassium	151	115	118	130	25	104	86	42
Calcium	60.8	53.7	41.5	33.9	41.6	46.8	24.4	59.2
Magnesium	16.7	17.9	9.6	21.2	8.9	8.5	8.4	18.4
Copper	0.205	0.074	0.567	−0.056	0.152	0.253	0.445	0.047
Manganese	7.05	0.91	5.48	8.34	−0.60	8.99	−0.28	14.57
Zinc	0.61	0.99	0.49	0.47	0.33	0.50	0.71	0.49
Boron	0.249	0.285	0.208	0.333	0.073	0.147	0.212	0.282

CONCLUSIONS

The results of this study indicated that whole-tree harvesting of close-spaced plantations of *P. radiata* would more than double the rate of nutrient removal from the site compared with intensive harvesting of conventional wider-spaced plantations. It would be desirable to be able to model nutrient removal under a variety of silvicultural systems and harvesting intensities and on a range of site qualities. While this paper provides additional data towards that end, there remain considerable gaps in our knowledge of the nutrition of *P. radiata* plantations. We believe that the importance of *P. radiata* to the forestry economy in the Southern Hemisphere is such that co-operative research to obtain the necessary data for nutritional modelling is warranted.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the 1980 laboratory analyses by Suzanne Gallagher.

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