NUTRIENT CONCENTRATIONS WITHIN STEMS OF PINUS RADIATA

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ABSTRACT

Nutrient concentrations in both stemwood and stembark were plotted against stem diameter and tree age and regressions were calculated which may be combined with stem taper equations and wood density to predict nutrient removal in stemwood under a range of harvesting scenarios for the central volcanic plateau of New Zealand.

Keywords: wood; bark; nitrogen; phosphorus; potassium; calcium; magnesium; manganese; zinc; **Pinus radiata**.

INTRODUCTION

In order to estimate nutrient removals in harvesting it is necessary to estimate the nutrient contents of harvested material. Most existing estimates are based on only one harvesting scenario (Freedman 1981). To be of greatest use, estimating techniques must allow for a variety of harvesting options including a range of utilisation limits. As part of the development of a flexible system of estimating nutrient removals in stemwood harvesting systems, we have examined the relationships between log diameter, tree age, and stem nutrient concentrations.

Orman & Will (1960) examined four nutrients in stems of *Pinus radiata* D. Don. They concluded that nitrogen, phosphorus, and potassium concentrations in wood increased with height in the tree and decreased from sapwood to heartwood. In contrast, calcium concentrations were highest in heartwood at the butt. Nutrient concentrations in bark were higher in living than in dead tissue. Nitrogen, phosphorus, and potassium had similar patterns with little variation in living bark within the tree but with increasing concentrations in dead bark up the stem. Calcium concentrations in living bark decreased up the stem but variation in dead bark was relatively minor. These patterns are consistent with decreasing concentrations of nitrogen, phosphorus, and

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potassium and increasing concentrations of calcium with aging tissue. They result in two distinctly different types of relationship between stem diameter and nutrient concentration.

Data on the variation of nutrient concentrations within stems of *P. radiata* have been collected in three studies of biomass in the central North Island of New Zealand (Table 1). This paper combines previously unpublished data from these studies to obtain relationships between stem diameter and nutrient concentrations in wood and bark.

MATERIALS AND METHODS

A total of 196 wood and 136 bark samples was available from 29 and 24 trees, respectively (Table 1). The trees ranged in age from 4 to 29 years and the number of samples per tree varied from a minimum of five in the 29-year-old trees to a maximum of 19 in the 22-year-old tree. Each sample was representative of a 10-cm-thick disc sawn from the stem at intervals from the butt to the top of the tree. Stem samples varied in diameter outside bark from 2.6 to 56.2 cm. Diameter and tree age were correlated ($r = 0.55$ for the wood samples). Data were available for seven elements (nitrogen, phosphorus, potassium, calcium, magnesium, zinc, and manganese) for all samples. Sulphur analyses were available for the 8-year-old trees only.

TABLE 1–Tree age, stem diameters, numbers of observations, and sources of data

Tree age (years)	Stem diameter		No. of samples		Reference
	Minimum (cm)	Maximum (cm)	Wood	Bark	
4–22	4.5	48.2	60	0	Madgwick *et al.* (1977)
8	2.6	27.7	61	61	Frederick *et al.* (1985)
29	3.9	56.2	75	75	Webber & Madgwick (1983)

The study sites were in the central North Island of New Zealand at Kaingaroa Forest (Madgwick *et al.* 1977; Webber & Madgwick 1983) and on NZ Forest Products Ltd land near Mangakino (Frederick *et al.* 1985). All sites had deep volcanic soils with site indices of over 30 m at age 20 years and were characteristic of the central volcanic plateau of the North Island of New Zealand. Stem discs were separated into wood and bark fractions and oven-dried at either 60°C (Madgwick *et al.* 1977) or 70°C (Webber & Madgwick 1983; Frederick *et al.* 1985) before being chipped and ground for chemical analysis. Methods of chemical analyses varied among the three studies and are detailed in the original publications.

Nutrient concentrations were plotted against stem diameter for each age-class of tree and against tree age for each of four 5-cm-diameter classes for which at least four ages were represented. Examination of these graphs led to the selection of regressions to relate nutrient concentrations to stem diameter and tree age. Regression coefficients were calculated after logarithmic transformation. The intercepts have been corrected for the bias due to transformation (Patterson 1966).

RESULTS AND DISCUSSION

Nutrient concentrations within the two types of tissue tended to be correlated (Table 2). Correlations among nitrogen, phosphorus, potassium, magnesium, and zinc, were all positive in both wood and bark. These five elements were positively correlated with calcium and manganese in bark but negatively correlated in wood.

TABLE 2—Correlation coefficients for stemwood nutrients (upper right triangle) and stembark nutrients (lower left triangle) based on 196 and 136 samples, respectively. Values exceeding 0.18 for stemwood and 0.22 for stembark are significant at the 1% level assuming independent tests

	N	P	K	Ca	Mg	Zn	Mn
N		0.90	0.94	–0.39	0.75	0.72	–0.43
P	0.90		0.88	–0.22	0.73	0.70	–0.41
K	0.78	0.83		–0.38	0.74	0.71	–0.39
Ca	0.07	0.13	0.06		–0.12	–0.25	0.09
Mg	0.59	0.71	0.69	0.49		0.70	–0.46
Zn	0.34	0.49	0.55	0.16	0.58		–0.51
Mn	0.26	0.40	0.44	0.50	0.66	0.59	

Two distinctly different patterns relating nutrient concentration to stem diameter were observed (Fig. 1, 2; Table 3). For all elements in bark and for five elements in wood (nitrogen, phosphorus, potassium, magnesium, and zinc) nutrient concentration decreased with increasing diameter. Usually this relationship was exponential. For calcium and manganese in wood, concentrations within trees were poorly related to stem diameter. Standard errors of estimate for log-log regressions indicated that, within an age-class, stem diameter could be used to estimate nutrient concentrations within the range 67% to 150% one-third of the time.

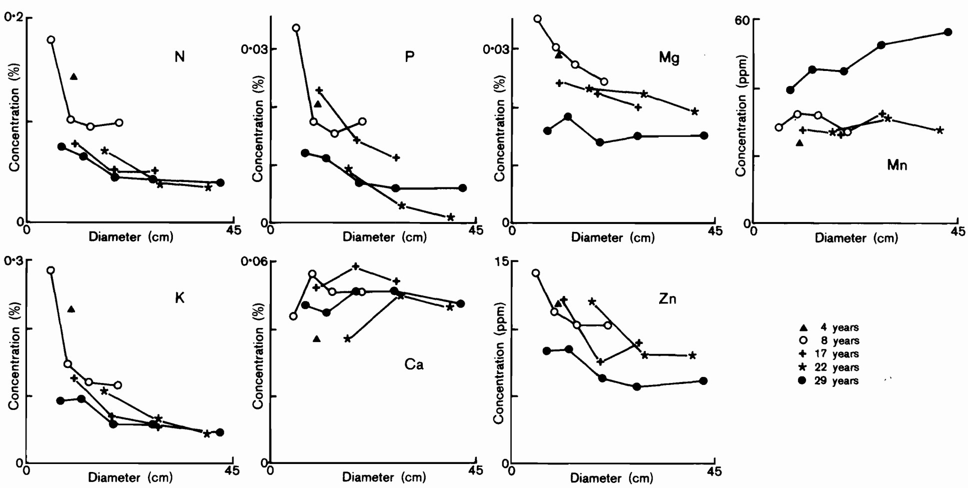

FIG. 1—The relationship between mean nutrient concentrations by tree age-class and stem diameter for stemwood.

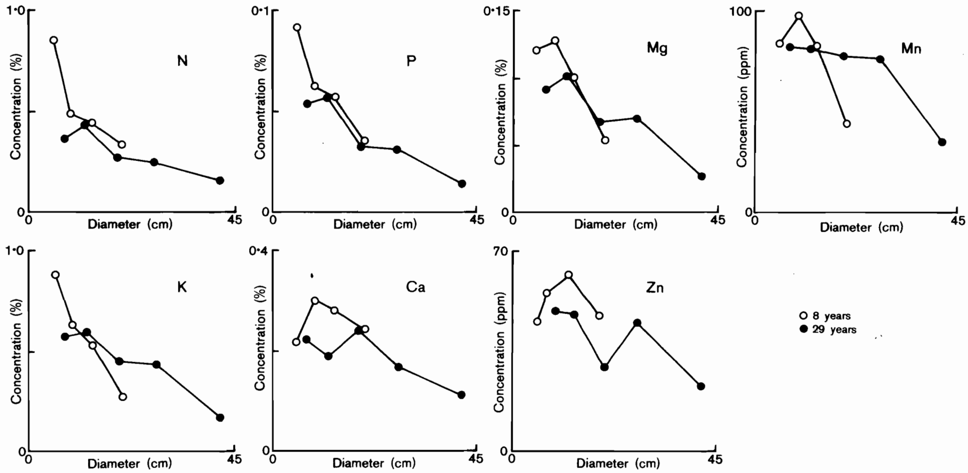

FIG. 2—The relationship between mean nutrient concentrations by tree age-class and stem diameter for stembark.

TABLE 3–Regression constants for estimating nutrient concentrations in stemwood (Y) from diameter (D in cm) and tree age (A in years) using equations of the form $\ln(Y) = a_0 + a_1.\ln(D) + a_2.\ln(A)$ and $\ln(Y) = b_0 + b_1.\ln(D.A)$ together with their standard errors of estimate (S.E.). "Missing" coefficients indicate non-significant regression coefficients

Nutrient	a_0	a_1	a_2	S.E.	b_0	b_1	S.E.
N (%)	–0.35	–0.433	–0.409	0.25	–0.35	–0.421	0.25
P (%)	–1.65	–0.664	–0.346	0.54	–1.63	–0.507	0.54
K (%)	0.25	–0.527	–0.398	0.36	0.26	–0.463	0.36
Ca (%)	–3.04	–	–	–	–	–	–
Mg (%)	–2.45	–	–0.500	0.41	–2.37	–0.265	0.42
Mn (ppm)	2.65	–	0.332	0.31	2.60	0.177	0.32
Zn (ppm)	3.50	–0.216	–0.259	0.30	3.50	–0.237	0.30

Two separate relationships between nutrient concentration and tree age within diameter classes were also observed for wood (Fig. 1; Table 3). For five elements (nitrogen, phosphorus, potassium, magnesium, and zinc), age and concentration were negatively correlated. For manganese this correlation was positive owing to the high concentrations in the 29-year-old compared with the younger trees. Calcium concentrations were unrelated to tree age.

The data could be summarised by regressions relating nutrient concentrations in stemwood to tree age and stem diameter using either the form

$$\ln\ (\text{concentration}) = a_0 + a_1 . \ln\ (\text{diameter}) + a_2 . \ln\ (\text{age})$$

or

$$\ln\ (\text{concentration}) = b_0 + b_1 . \ln\ (\text{age} . \text{diameter})$$

which both gave very similar estimates of intercept and of standard error of estimate (Table 3). For nitrogen, potassium, calcium, and zinc plotting the family of curves using a range of ages and diameters indicated very similar estimates of concentration irrespective of the form of the equation chosen. For phosphorus, magnesium, and manganese the two sets gave dissimilar curves but within the range of ages and diameters sampled no clear choice of the "best" form could be determined.

Concentrations of macronutrients reported for *P. radiata* stemwood in Australia (Stewart *et al.* 1981) are similar to those found in the central North Island of New Zealand but reported trace element concentrations in Australian material appear lower (Hatch & Mitchell 1972; Stewart *et al.* 1981). The equations presented in Table 3 will be applicable only to sites similar to those sampled – namely, productive stands on the central volcanic plateau of the North Island of New Zealand. The form of the equation may have wider applicability. The equations may be combined with stem taper equations (Gordon 1983) and wood density (Cown & McConchie 1982) to estimate the distribution of nutrient contents within *P. radiata* stems for this limited range of sites.

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