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SEASONAL AND BETWEEN-TREE VARIATION IN THE NUTRIENT LEVELS IN *PINUS RADIATA* FOLIAGE

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ABSTRACT

Seasonal trends in the concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) in the foliage of 7- to 9-year-old *Pinus radiata* were followed at four sites in New Zealand, revealing large seasonal changes which also usually differed with site. N, P, K, and Mg concentrations were low in mid-summer with a rise, except for P, later in the growing season. Ca levels rose steadily as the foliage aged.

Between-tree nutrient variation was lower for first-year foliage than for that in its second growing season. In first-year foliage, N and P tended to have a lower coefficient of variation in summer than in winter but the opposite was true for K. For between-tree variation within seven dominants on each of 127 sites throughout New Zealand the coefficient of variation averaged 8.5, 13.8, 15.6, 24.0, and 20.4% for N, P, K, Ca, and Mg, respectively. Sampling intensity required to detect differences of 10 and 20% of the mean varied widely with the element; for most studies a minimum of 10 trees should be sampled at each site.

For *Pinus radiata* in New Zealand collection of mature-length foliage of the current growth year from upper crown second-order branches is recommended. For N, the sample should be collected from late January to March; for P, from late January to May; for K, from March to May; for Ca, March to June; and for Mg in January. A compromise for all five elements is to collect between late January and March.

INTRODUCTION

The very important role of fertilisers in increasing plant crop production has led to development of specialised soil extraction and analysis techniques. Soil analyses are extremely valuable and are used on a large scale in agriculture for forecasting fertiliser needs but are an indirect means of estimating the quantities of nutrients available for uptake by plants. For established crops, analysis of foliage or other plant tissues can give, in many cases, a more direct and better measure of what the plant is actually extracting from the soil.

Foliage analysis has become the major tool in assessing the adequacy of nutrient supplies to trees, both for detecting nutrient deficiencies and monitoring the effectiveness of fertilisers. It is also well known that foliage nutrient concentrations vary between trees with age of foliage, position in the tree crown, and season of the year (White, 1954; Tamm, 1955; Will, 1957; Wells and Metz, 1963; Lowry and Avard, 1968; 1969; Miller, 1966; Everard, 1973; Mead and Pritchett, 1974).

To reduce variations from these factors to a minimum, standard sampling procedures have been adopted by most research workers. For conifers, that most frequently used involves the current season's foliage of the top whorls during autumn or winter (White, 1954; Tamm, 1955; Wells and Metz, 1963; Lowry and Avard, 1969; Everard, 1973). However, some workers have questioned whether this sampling scheme is the most sensitive for detecting site or fertiliser treatment differences (Lowry and Avard, 1969; Mead and Pritchett, 1974).

A study by Will (1957) and consideration of the practical problems of collecting foliage from older trees led to the development of a standard sampling procedure in New Zealand which differs from those usual in most other countries. Foliage is collected from several second-order branches on different sides of the crown and about one-third down the green crown. Mature-length foliage is collected from the current season's growth, preferably in summer to early autumn. It is known that this is the time of year when trees can be under greatest nutrient stress as indicated by decreases in the nutrient content of older foliage (Tamm, 1955).

This standard New Zealand sampling scheme has been used since the mid-1950s to detect nutrient deficiencies (Will, 1965; 1966; Stone and Will, 1965a; 1965b), to relate tree growth to foliage levels (Ballard, 1970) and to follow fertiliser uptake (e.g., Will, 1965; Jacks *et al.*, 1971) in *Pinus radiata* D. Don. In recent years, foliage analysis has been used for prescribing when phosphate or boron fertilisers should be applied to stands of radiata pine. The procedure is well accepted and is now prescribed in management plans for certain regions.

The objectives of the present study were to determine:

- (1) Seasonal changes in nutrient concentrations in the foliage.
- (2) Influence of site on these seasonal changes.
- (3) The number of trees that need to be sampled to obtain a reasonable estimate of the nutrient levels.
- (4) According to the results obtained, amend and redefine the New Zealand sampling procedure.

METHODS

Seasonal trends

The seasonal variations in N, P, K, Ca, and Mg were followed in 8-10 co-dominant trees on each of four sites. These sites, designated A to D—Riverhead, Woodhill, Kaingaroa, and Tasman (Nelson) forests, respectively—cover a fairly wide range of soils and, to a lesser degree, the climatic conditions in which *P. radiata* is planted in New Zealand. The trees varied between 7-9 years of age and from 7-14 m mean height and were taken from an area of about 0.05 ha at each site.

Foliage samples were collected at intervals of 3-9 weeks over a period of about 12 months in 1966-67. On three of the eight sampling occasions—June (first winter), December, and June (second winter)—all trees were sampled. Three trees at each site were selected for sampling on intermediate sampling dates: this was done to reduce analytical work.

Foliage was collected from second-order branches on all sides of the crown of each tree. The same whorl was sampled each time. This marked whorl had originated in the spring two seasons prior to the start of the experiment and, when sampled, was 4-6 whorls from the top. Only the longest needles in the major flush of a given year's growth, were collected. In this paper "young" foliage refers to needles in their first growing season—collected from early summer until the middle of the following winter. "Older" foliage denotes foliage in its second year and this was collected from mid-winter to mid-winter (Fig. 1).

The analysis of variance of the nutrient concentrations used the method of fitting constants (Bancroft, 1968) in order to overcome unequal subclass numbers. A random model was assumed.

Between-tree variation and sampling intensity

Between-tree variation was calculated for those sampling dates on which foliage was collected from all trees. A more comprehensive study was made using individual tree data from a study on the relationships between site factors and *P. radiata* growth (Jackson and Gifford, 1974). In that study young foliage was collected from the seven tallest trees in each 0.04-ha plot. The 127 plots that were sampled were located throughout New Zealand, covering a wide range of climatic and soil conditions. Very phosphate- and boron-deficient soils were not included in the study.

In order to differentiate between actual variation in nutrient content between trees and uncertainty in chemical analysis, an assessment of the reproducibility of the method was needed. This was obtained by repeat analyses (by several different operators) of a single standard foliage sample.

The sampling intensities required to detect 10 and 20% differences between two means, at a 95% confidence level, were calculated as described by Steyn (1961).

Analytical techniques

Foliage N concentration was determined by a micro-Kjeldahl technique using a selenium catalyst and steam distillation. For P, K, Ca, and Mg a separate subsample was ashed at 450°C and dissolved in HCl. P was determined by the vanadomolybdate colorimetric method and K, Ca, and Mg by atomic absorption spectroscopy using SrCl₂ to suppress interference.

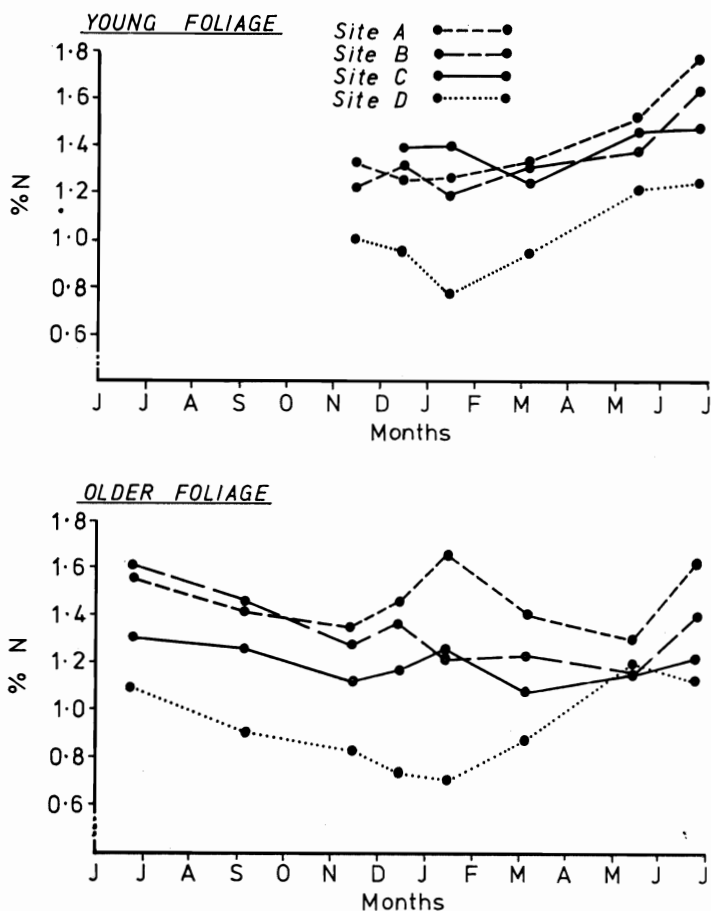


FIG. 1—Seasonal trends for nitrogen in radiata pine foliage.

RESULTS

Seasonal trends

Nitrogen

The concentration of N in the young foliage decreased during the summer and rose again in autumn (Fig. 1). In the second growing season levels fell in the spring and generally rose in late autumn, although in one case there was a summer peak. The significant site \times season interaction (Table 1) resulted from the differences in the seasonal pattern on different sites.

Phosphorus

The concentration in young foliage showed a rapid drop in mid-summer (Fig. 2) but was stable, with one exception, after January. The older foliage also showed large seasonal fluctuations and foliage of both ages had significant site \times season interactions (Table 1). It is interesting to note that fluctuations in P levels in older foliage were smaller on the two sites where overall levels of P were low.

TABLE 1—Summary of analysis of variance of seasonal and site influences on *P. radiata* foliage nutrient concentrations

Needle age	Source	d.f.	Element concentration				
			N	P	K	Ca	Mg
			Significance				
Young (first growing season)	Season	5	†	†	†	†	*
	Site	3	†	†	*	†	†
	Season × site	15	†	†	†	†	*
Older (second growing season)	Season	7	*	†	†	†	†
	Site	3	†	†	N.S.	†	†
	Season × site	21	†	*	†	†	N.S.

N.S. Not significant at 5% level

* Significant at 5% level

† Significant at 1% level

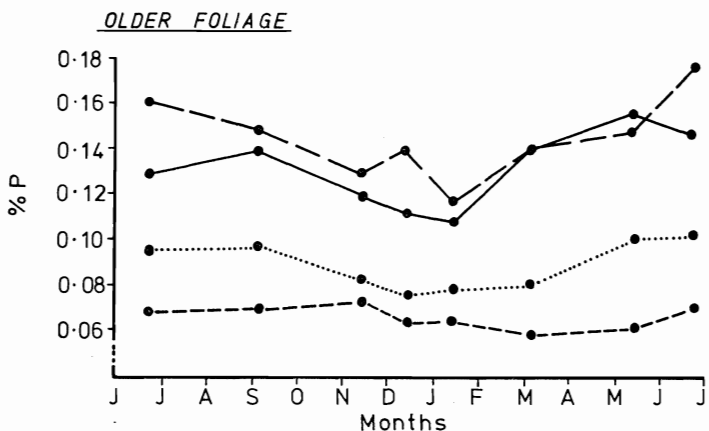
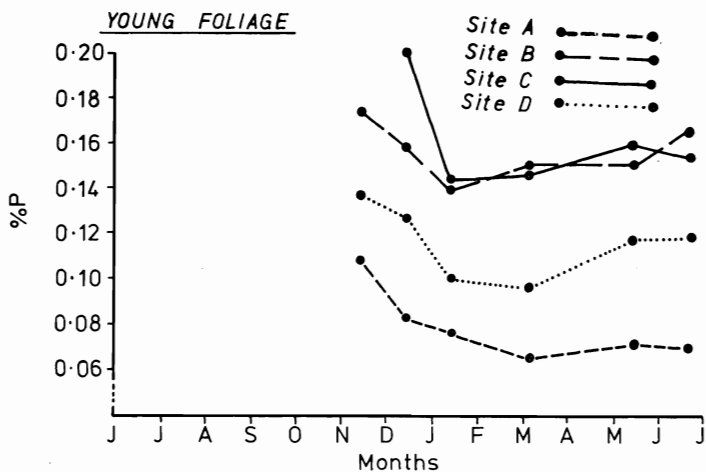


FIG. 2—Seasonal trends for phosphorus in radiata pine foliage.

Potassium

The seasonal trends were similar to those for N, the concentration falling to a minimum in mid-summer (Fig. 3). Interactions between season and site were significant (Table 1).

Calcium

The general tendency was for the concentration of this nutrient to increase as the foliage aged (Fig. 4). Because the rate of increase differed from site to site, the interaction between season and site was again significant (Table 1).

Magnesium

On two sites there was a drop in Mg concentration in the young foliage during mid-summer (Fig. 5), while on the other two sites there was a steady increase during the growing season. In the older foliage all sites had their lowest level in spring-summer. The interaction between sites and season was not significant in this older foliage (Table 1).

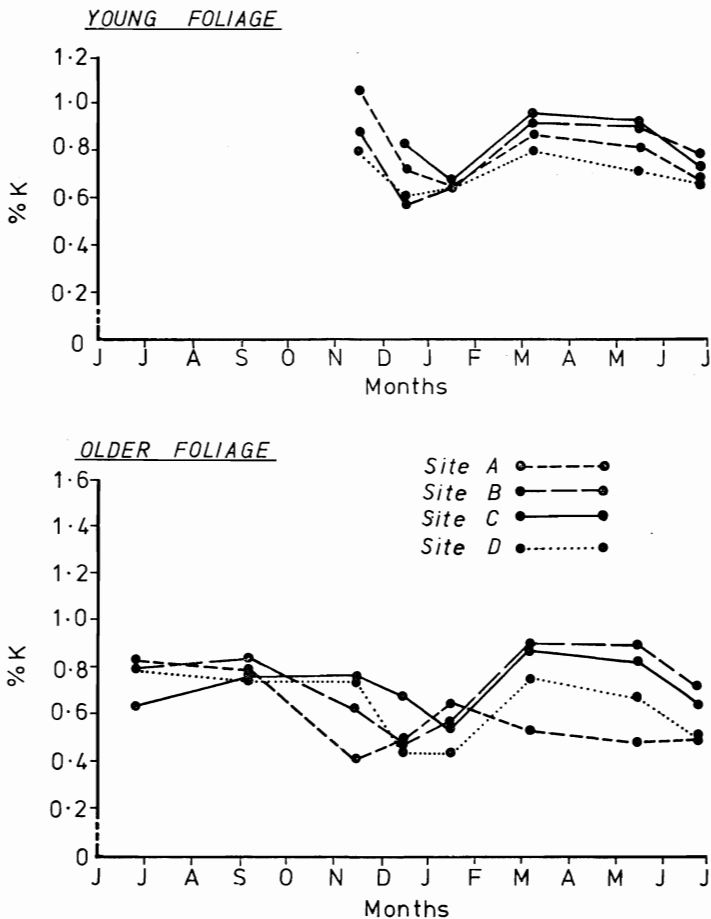


FIG. 3—Seasonal trends for potassium in radiata pine foliage.

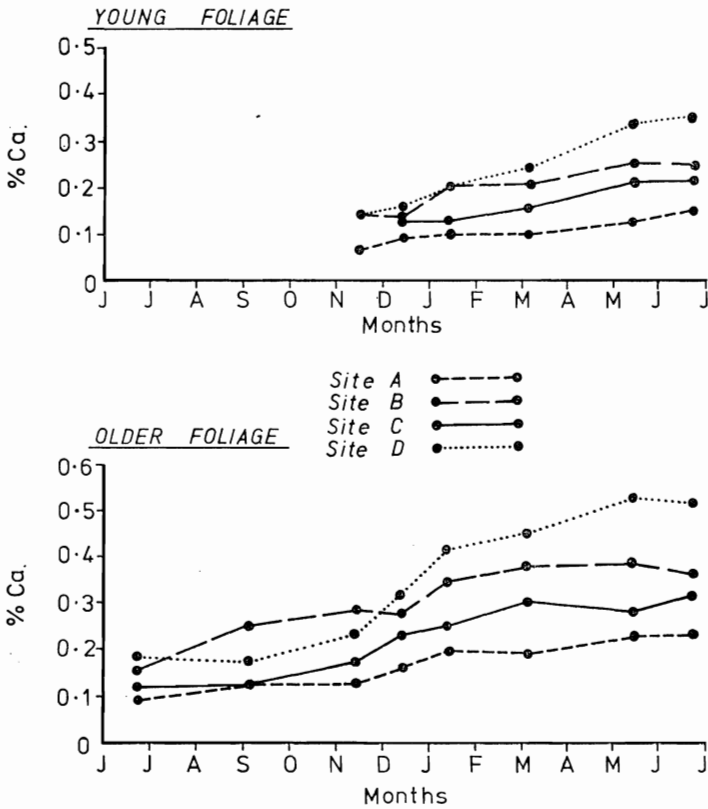


FIG. 4—Seasonal trends for calcium in radiata pine foliage.

Between-tree variation

The between-tree variation, at the sites used to study seasonal trends (Table 2), varied greatly with nutrients and, to a lesser extent, with sampling date and site. The lowest variation was associated with N and P. There was a tendency for the between-tree variation of N and P in young foliage to be lower in the summer than in the winter, but the reverse was true for K. Older foliage tended to have higher variability than young foliage when sampled at the same time of the year.

The mean between-tree variations for the 127 plots spread throughout New Zealand were of a similar order to those obtained in the seasonal study, but the range was greater (Table 3). There was only a weak correlation (often negative) between the average nutrient concentration in the plot and its coefficient of variation.

DISCUSSION AND CONCLUSIONS

The large seasonal fluctuations found for all nutrients at all sites are similar to those found in other species (White, 1954; Wells and Metz, 1963; Lowry and Avard, 1969; Mead and Pritchett, 1974). An important feature of our results is the site \times season interaction which shows that seasonal changes do not follow the same patterns on

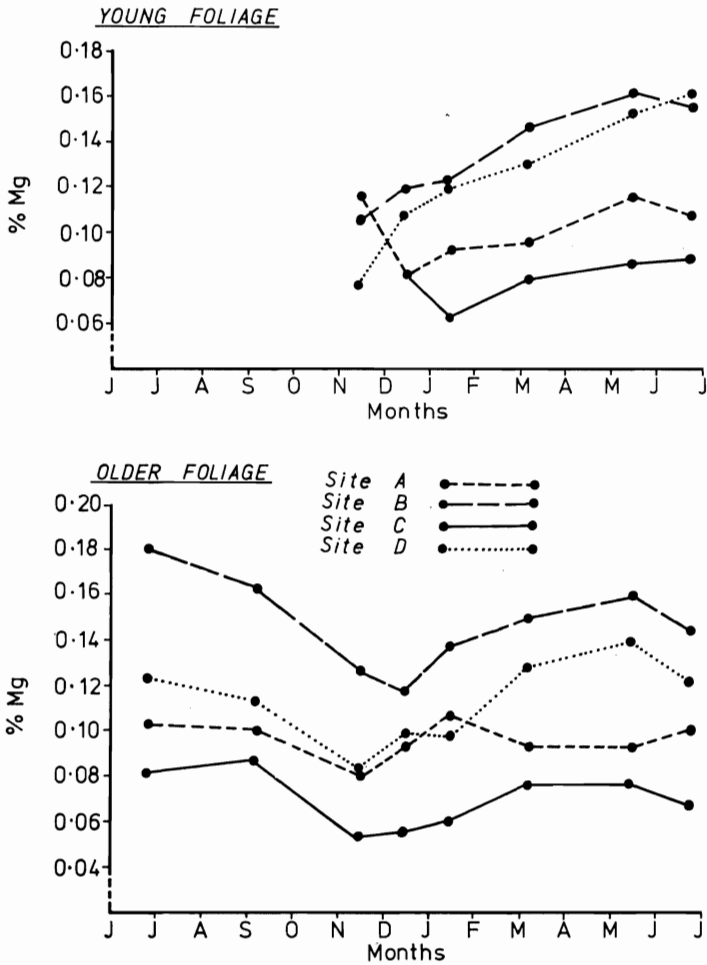


FIG. 5—Seasonal trends for magnesium in radiata pine foliage.

TABLE 2—Between-tree variation in foliage nutrient concentration as influenced by sampling date¹

Sampling Date	Element Concentration				
	N	P	K	Mg	Ca
C.V.%					
Young foliage					
December	6.4 [†]	9.4 [†]	17.1	19.7	24.3
June	9.3	11.4	11.9*	20.8	23.4
Older foliage					
June (1st year)	7.2	10.4	13.7	21.2	23.7
December	6.8	12.7	12.8	24.3	27.6
June (2nd year)	9.8	15.3	25.8	26.6	24.7

¹ Between-tree variation figures include the variation in the chemical analysis
 * Significantly lower at 5% level
 † Significantly lower at 10% level

TABLE 3—Foliage nutrient concentration and variations for 127 plots throughout New Zealand

Element	Concentration (%)		C.V. (%)		Correlation (r) between con- centration and C.V.	*Number of trees to detect differences be- tween mean values of	
	Mean	Range	Mean	Range		10%	20%
N	1.51	0.85 - 2.27	8.5	1.8 - 23.8	-0.28	4	1
P	0.13	0.07 - 0.24	13.8	0.0 - 47.0	0.08	11	3
K	0.73	0.39 - 1.10	15.6	3.5 - 40.3	-0.22	14	4
Ca	0.25	0.11 - 0.56	24.0	9.5 - 67.9	0.04	35	9
Mg	0.15	0.05 - 0.24	20.4	4.3 - 43.7	-0.21	24	6

* The C.V. for the chemical-analysis technique is deducted from the total C.V.% before calculating these sample sizes (see Steyn, 1961). These chemical-analysis C.V.% were 2.0, 2.1, 2.2, 2.6, and 2.8 for N, P, K, Ca, and Mg, respectively.

different sites in New Zealand. Thus, there is no simple way in which foliage samples taken from different sites at different times of the year can be exactly related to each other. The best alternative is to restrict sampling to a defined period of time each year.

The most suitable period to take foliage samples should be when:

1. Foliage nutrient differences between sites (and/or treatments such as fertilisers) are greatest, thus giving highest sensitivity in detecting deficiencies.
2. Between-tree variability is minimal.
3. There is minimal change in nutrient concentrations over a reasonable period of time.

Evidently (*see* Table 4) there is no single, relatively short, period of the year during which all these conditions are fulfilled. Therefore some compromise is needed to select a standard foliage-sampling time. For particular studies and nutrients it is not strictly necessary to choose the same time of the year, but for most practical purposes there are considerable advantages if a standard sampling time is adopted.

The time to detect nutrient deficiencies and site differences with most sensitivity

TABLE 4—Summary of criteria used to select "best" foliage sampling time

Element	Sensitivity to nutrient deficiencies		Minimum between-tree variability		Stability of element content	
	Time	Foliage Age	Time	Foliage Age	Time	Foliage Age
N	Jan	Both ages	Summer*	Young	Dec - March*	Young
P	Jan - June	Young	Summer*	Young	Jan - May	Young
K	March - May	Both ages	Winter	Young	March - May	Both ages
Ca	March - June	Older	—	Young	March - June†	Both ages
Mg	Dec - Jan or Jan - May	Young Older	—	Young	March - May†	Both ages

* Distinction not clear.

† Stability poor due to tendency to increase as foliage ages

should be when the trees are under maximum stress, i.e., the middle of the growing season. In this study the seasonal trends for P and K show that they are at low levels at that time of year; at two of the four sites there is also a suggestion of N and Mg stress in the summer. For N, differences between sites were greatest in summer but for the other nutrients autumn and winter sampling tended to have the advantage of revealing greater between-site differences. For sensitivity in detecting site differences Lowry and Avard (1969) found that for *Pinus banksiana* (but not spruce) it is best to sample N, P, and K during the growing season, and Ca and Mg in winter.

In the present study, between-tree variability was lower in young foliage than in the older foliage. Lowry and Avard (1969) describe a similar situation. In young needles, K has a lower between-tree variability in winter than summer; there is an indication that the opposite is true for N and P.

The most stable periods of the year also vary with the nutrient concerned. For N there did not appear to be any period which was particularly stable. The most stable period for P was between January and May, and for K, Mg, and Ca between March and May. More frequent sampling may have defined the stable periods better, although changes in growth due to climatic factors may have prevented this (Miller, 1966).

The recommended sampling periods, based on the above considerations, are:

N — young foliage collected in January to March.

P — young foliage collected in January to May.

K — young foliage collected in March to May.

Ca — young foliage collected in March to June.

Mg — young foliage collected in January or older foliage collected in March to May.

A practical compromise, that restricts sampling to one age of foliage and covers a period of time in which it is possible to carry out a foliage-sampling programme covering different parts of the country, is to collect young foliage between late January and March. This is essentially the sampling procedure previously adopted.

In order to detect a significant difference of a given size between two samples, the number of trees needed per foliage sample varies widely with the element being studied (Table 3). These sampling intensities are of a similar order to those described by Lowry and Avard (1969) for black spruce and jack pine, by Mead and Pritchett (1974) for slash pine, and by Wehrmann (1959) for Scots pine.

This type of information is essential for developing sampling schemes for various types of studies, but it must be remembered that these data are from co-dominant and dominant trees sampled from fairly small plots. More variability might be expected when samples are collected over a larger area, or when all crown classes are included.

Sampling for general experimental purposes or management recommendations requires a minimum of 10 trees, and 15-25 where possible.

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