VARIATION IN NUTRIENT CONCENTRATIONS WITHIN *PINUS RADIATA* TREES AND THEIR RELATIONSHIP TO TREE SIZE

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ABSTRACT

Twelve *Pinus radiata* D. Don trees were sampled for concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in foliage by age and crown location, in branches by age, and in stem sections. Crown component nutrient concentrations were more highly correlated with diameter breast height than with either total height or height increment. Foliar nitrogen and phosphorus decreased and calcium and magnesium increased down the crown. Foliar nitrogen and phosphorus decreased and calcium increased with needle age. Branch nitrogen, phosphorus, and potassium decreased and calcium increased with both branch age and stem diameter.

Coefficients of variation in foliar nutrients tended to be lowest in 1-year-old foliage. Among nutrients the coefficients were lowest for nitrogen and phosphorus and highest for calcium and magnesium.

Keywords: nitrogen; phosphorus; potassium; calcium; magnesium; needles; branches; stems; *Pinus radiata*

INTRODUCTION

Information on variability of nutrient concentration within trees and among trees within a stand is important in determining sampling strategies for diagnostic purposes (Raupach *et al.* 1972) and in the study of nutrient cycling (Mead 1984).

Many earlier studies involved few trees and lacked statistical analysis. Studies of the nutrient content of whole trees and stands have provided estimates of average nutrient concentrations of whole crowns but such data have not been related to foliage data collected from specific locations in the crown for diagnostic purposes.

Foliar concentrations of nitrogen, phosphorus, and potassium decrease with increasing needle age (Will 1957; Madgwick *et al.* 1977) and with distance from the tree top (Will 1957; Raupach 1974; Madgwick *et al.* 1983) in *P. radiata,* while calcium shows opposite trends. However, studies of trends in foliar nutrient concentrations within tree crowns suggest that position effects are not consistent (Morrison 1974; Madgwick *et al.* 1983). Within stands, foliar nutrient levels are related to tree size and leader growth in a variety of species (Leyton 1956; Leyton & Armson 1956; Madgwick 1964).

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Nutrient concentrations in *P. radiata* branches and stems usually decrease as trees age (Madgwick *et al.* 1977; Madgwick 1985). The effects of branch age on nutrient concentration have not been reported for *P. radiata* but are important in estimating nutrient cycling as affected by the use of live crown pruning. Within stem wood and bark, concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium all decrease with increasing stem diameter except that concentration of calcium in wood is not related to diameter (Orman & Will 1960; Madgwick & Frederick 1988).

We have examined the variation in nutrient concentrations within each age-class of foliage and branches and within stems of 12 trees sampled at the commencement of a thinning × fertiliser interaction experiment (Mead *et al.* 1984). These data allow an examination of nutrient variation and are a basis for following subsequent changes within the stand after treatment.

MATERIALS AND METHODS

Details of the experimental site in Eyrewell Forest near Rangiora have been given by Mead *et al.* (1984). Twelve sample trees were felled in September 1977, 7 years after planting, when the plantation had an average stocking of 1540 stems/ha, a basal area of 9.1 m^2/ha, and an average height of 5.3 m. The stand had been treated 3 months earlier with 75 kg phosphorus and 5 kg copper/ha as superphosphate and copper sulphate, respectively.

For each tree, total height, annual height increment, and diameter at breast height (dbh) were recorded. Branch age and weight (wood plus bark) and needle weights were recorded for each branch after drying at 70 °C. For each tree, branches of the same age were then combined to give samples of branch by age and of needles by branch age and needle age for chemical analysis. Stem needles were also kept separate by age.

The stems were divided into lengths corresponding to annual height increments within the crown, as determined by branch growth patterns, and the lower stem which was free of branches. Each segment was measured for length and for lower and upper diameters before being oven dried and weighed. Each segment was kept separate for subsequent chemical analysis.

Woody material was fragmented in a hammer mill before being ground in a Wiley mill. Subsamples were digested with H_2SO_4/H_2O_2 on a block digester, using selenium and lithium sulphate to accelerate oxidation, and analysed using the methods of Nicholson (1984). Nitrogen and phosphorus were determined by automated colorimetry and potassium, calcium, and magnesium by atomic absorption.

Correlations between crown tissue nutrient concentrations and tree size were calculated for each of the five nutrients using dbh, total height, and the last year's height increment as size variables for a total of 16 classes of tissue (three needle age-classes, four branch age-classes, and main stem needles).

Correlations among stem nutrient concentrations were calculated and the nutrient concentrations related to the average diameter of the relevant stem segment after logarithmic transformation.

RESULTS AND DISCUSSION

The sample trees varied in dbh from 5.0 to 12.0 cm and in total height from 3.75 to 6.05 m. Foliar concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium (percentage dry weight) in the 1-year-old foliage on 1-year-old branches averaged 1.6, 0.18, 0.76, 0.14, and 0.13 respectively, so were all at satisfactory levels according to the criteria of Will (1985) and in spite of subsequent positive growth responses to nitrogen fertiliser applications (Mead *et al.* 1984). Recommended sampling for diagnostic purposes in New Zealand is based on "full-length foliage taken in March from second-order branches in the top third of crowns of representative sample trees" (Will 1985). Our results could have been affected by sampling in winter–early spring (Mead & Will 1976) and also by including needles from all shoots. Unpublished data reported in a study of the effects of seasonal drought (Jackson *et al.* 1976) indicate that differences in concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium between first- and second-order shoots in *P. radiata* for any branch are numerically small and not statistically significant.

The magnitude and sign of the difference in nutrient concentrations in 1-year-old needles on the 1-year-old branches and the whole crown varied among nutrients depending on the gradient of concentration down the crown. The magnitude of differences indicates that the nutrient status of trees cannot be assessed from whole-tree sampling using conventional diagnostic criteria based on sampling at a specific location.

The patterns of nutrient concentrations in foliage confirm those previously published for *P. radiata* sampled in winter and spring (Will 1957; Hall & Raupach 1963; Raupach 1974; Raupach & Hall 1974; Madgwick *et al.* 1983). Foliar nitrogen and phosphorus each decreased and calcium and magnesium increased down the crowns irrespective of needle age (Fig. 1). Trends in potassium concentration were affected by needle age with significant decreases in concentrations within 1- and 2-year-old needles down the crown but with variable results for the older age-classes.

Possible needle-aging effects can be estimated by comparing needles developing in similar crown positions. For example, a comparison of concentrations in 1-year-old needles on 1-year-old branches with those in 2-year-old needles on 2-year-old branches indicated that nitrogen and phosphorus decreased consistently and calcium increased with increasing needle age. For magnesium, both on the main stem and within any one branch age-class, foliar concentrations consistently decreased with needle age but comparisons of needles developing in similar crown positions indicated variable effects of aging on foliar magnesium concentration. The results for potassium were inconsistent.

Coefficients of variation of foliar nutrient concentrations increased in the order nitrogen, phosphorus, potassium, magnesium, and calcium (Fig. 2). For nitrogen these coefficients ranged between 7% and 15% and there was relatively little difference between either needle age-classes or sampling positions. For the other four elements, coefficients of variation were usually lowest for 1-year-old needles and much more variable than those for nitrogen. The coefficients of variation for current foliage in the upper crown were similar to those found by Mead & Will (1976) and Knight (1978),

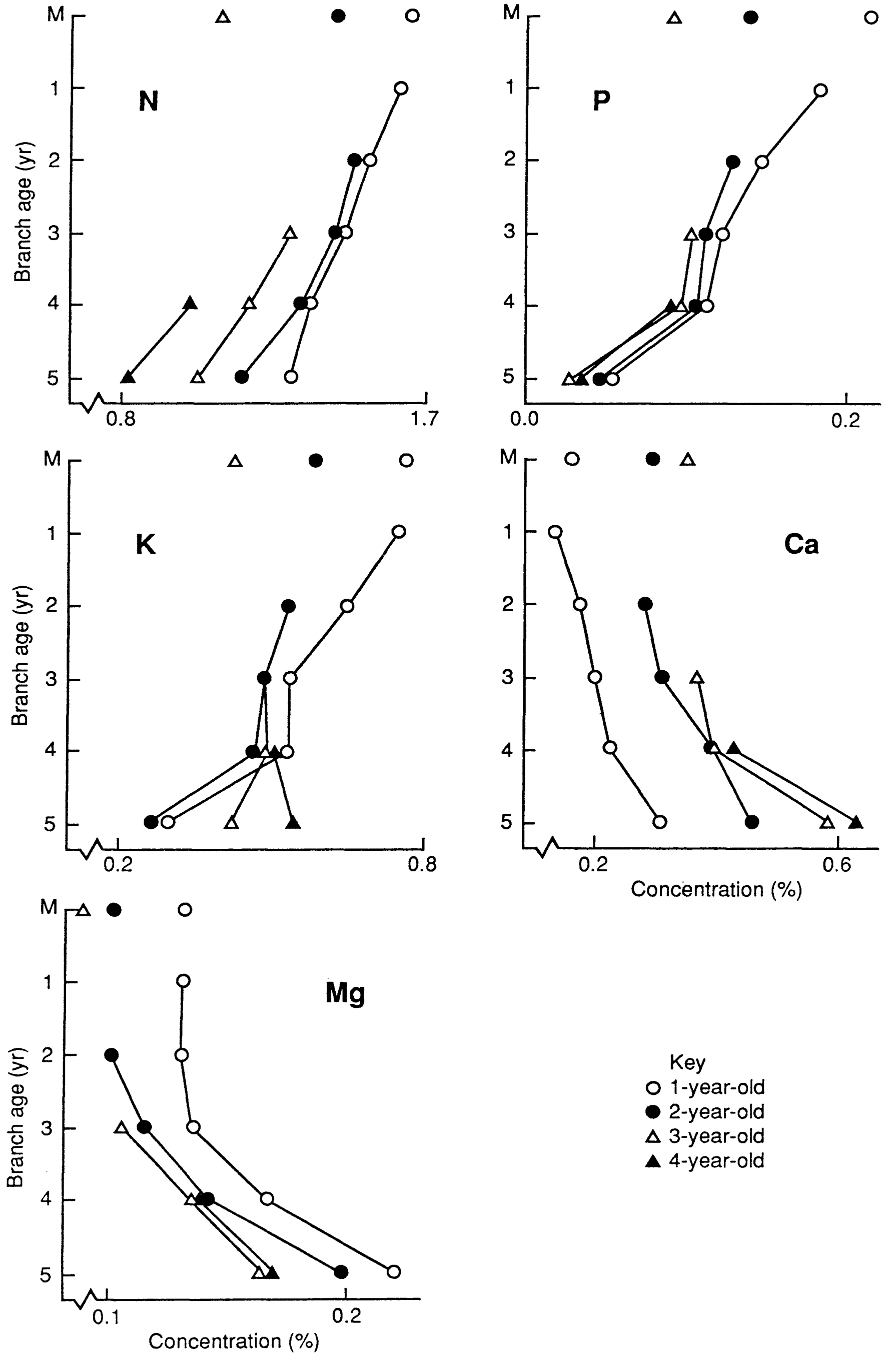

FIG. 1 — Relationship between nutrient concentration, needle age, and position in crown adjusted for tree effects based on the nutrient concentrations in 1-year-old needles on 1-year-old branches (M = main stem).

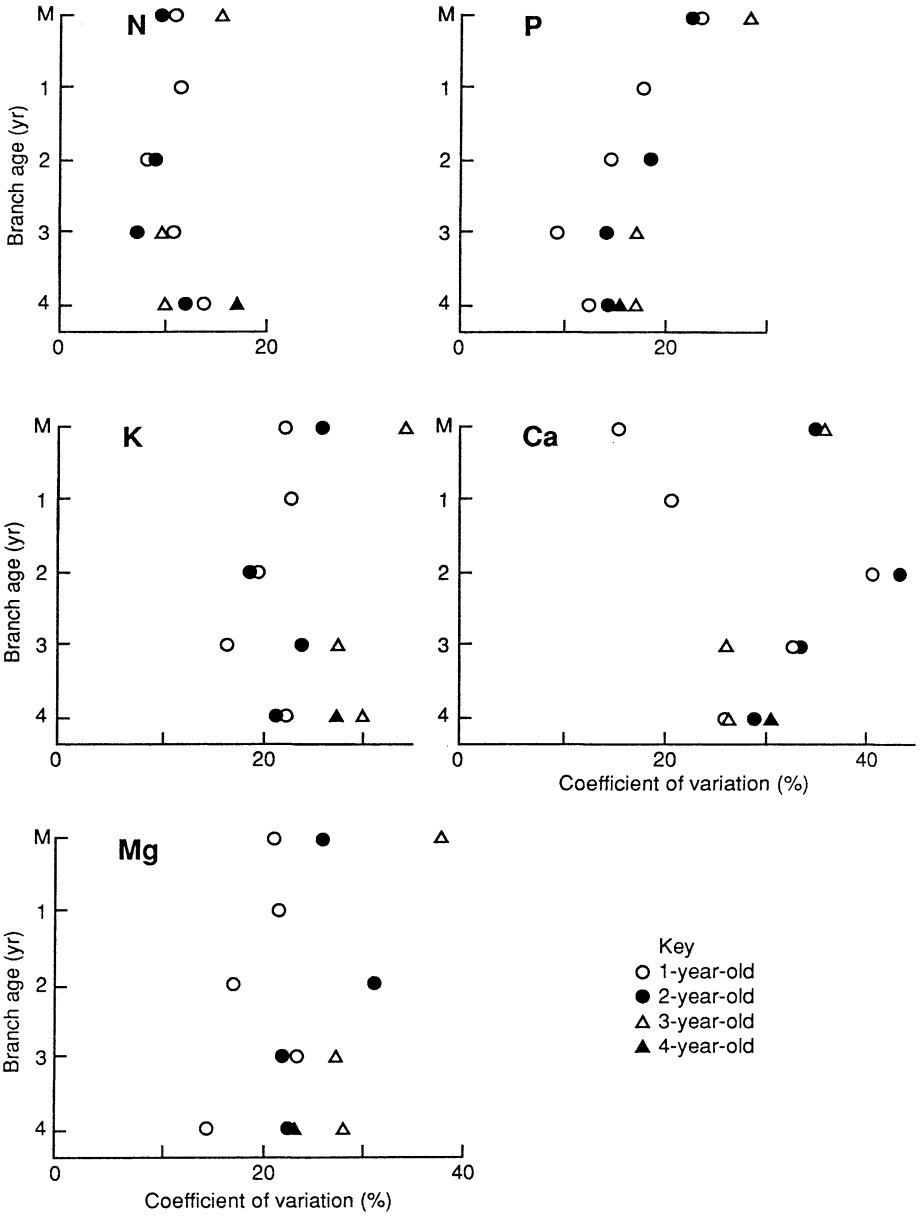

FIG. 2 — Coefficients of variation for needle nutrients by needle age and position in crown (M = main stem).

suggesting that they provide a satisfactory guide to the number of trees required for foliar sampling.

Correlation coefficients between nutrient concentrations in 1-year-old needles in the whole crown and in those on the 1-year-old branches at the top of the tree ranged between 0.54 and 0.94 (n = 12, r = 0.55, p = 0.05, Table 1). The ratio of average concentrations for the total crown to concentrations in the needles on 1-year-old branches ranged from 0.78 for phosphorus to 1.34 for calcium.

TABLE 1–Relationship between nutrient concentrations in 1-year-old needles for the whole crown and for needles on 1-year-old branches (n = 12, r = 0.55, p = 0.05)

Nutrient	Correlation coefficient	Average concentration	
		Whole crown	1-year branches
Nitrogen	0.91	1.51	1.63
Phosphorus	0.84	0.14	0.18
Potassium	0.94	0.62	0.76
Calcium	0.66	0.18	0.14
Magnesium	0.54	0.13	0.13

Branch nitrogen, phosphorus, and potassium concentrations all decreased with branch age, while calcium increased and magnesium remained approximately constant (Fig. 3). Differences between trees were significant for nitrogen, phosphorus, and potassium at the 1% level, while for calcium and magnesium probability levels were close to the 5% value.

The relationships between branch nutrient concentrations and branch age were not always the same as those reported for whole trees as trees age (Madgwick *et al.* 1977, 1988). Madgwick *et al.* (1977) reported decreases in nitrogen, phosphorus, potassium, and magnesium concentrations and increases in calcium in live branches with increased tree age in young stands. Except for magnesium, the effects of branch age found at Eyrewell were much greater than those found for tree age earlier. Madgwick *et al.* (1988) reported increases in concentration of all five nutrients in live branches with tree age though noting that their results were apparently affected by the location of sample trees. The substantial differences in nitrogen, phosphorus, potassium, and calcium concentrations in branches of different ages should be taken into account in modelling nutrient fluxes in stands subject to live crown pruning and whole-tree harvesting.

Nutrient concentrations in 1-year-old branches and their needles were correlated with those for phosphorus, potassium, and calcium exceeding the 1% probability level (Table 2). For nitrogen and magnesium the correlation coefficients just failed to reach the 5% probability level.

Diameter at breast height had the highest correlation with nutrient concentration in crown components (39 of 80 possibles), height increment next (25), and total height least (16) when each tissue type and nutrient was considered separately. Among nutrients, potassium had the highest correlation with growth variables (19 of 48) with the other four nutrients scoring between five (magnesium) and nine (calcium). For nitrogen, phosphorus, and potassium, dbh tended to be more highly correlated with

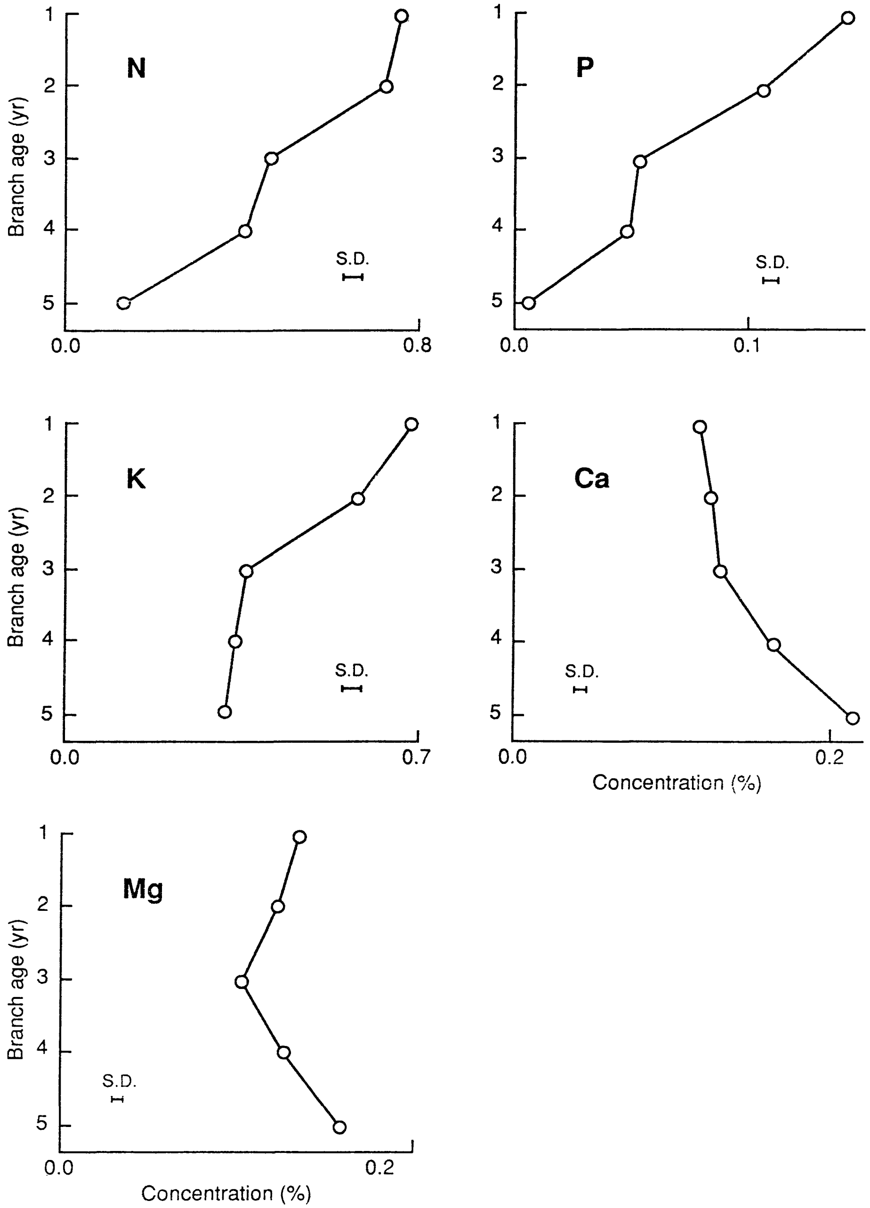

FIG. 3 — Relationship between branch age and nutrient concentrations adjusted for tree effects based on the nutrient concentrations in 1-year-old branches.

concentrations in branches (r ranging from 0.49 to 0.89) than in foliage (r 0.13 to 0.73). The number of positive correlations among the 36 coefficients relating foliar nutrients to tree size variables decreased in the order nitrogen (32), potassium (27), phosphorus (18), magnesium (7), and calcium (4). For phosphorus most of the correlations between

TABLE 2–Correlation between needle- and branch-nutrient concentrations in 1-year-old branches (n = 12, r = 0.55, p = 0.05).

Nutrient	Correlation coefficient
Nitrogen	0.55
Phosphorus	0.75
Potassium	0.71
Calcium	0.72
Magnesium	0.52

foliar nutrients and both total height and dbh were positive but those with height increment were negative.

Multiple regression of nutrient concentration on tree size variables as used by Leyton (1956) yielded no significant relationships using a 5% probability level in 22 of 48 possibles. Potassium was the element most frequently related to tree size (15) followed by calcium (10), nitrogen (6), and phosphorus and magnesium (3 each) in spite of relatively high concentrations of foliar potassium. Nitrogen fertiliser is known to increase diameter growth on this site (Mead *et al.* 1984) and it appears that correlations among concentrations of different nutrients and their differing coefficients of variation affect the outcome of multiple regression analysis (Madgwick 1964).

Within stems, concentrations of nitrogen, phosphorus, potassium, and magnesium were curvilinearly related to stem diameter (Fig. 4). Calcium concentrations were independent of stem size. Correlation coefficients between concentration and size (Table 3) were therefore calculated after logarithmic transformation. As a consequence nitrogen, phosphorus, potassium, and magnesium concentrations were all significantly interrelated with correlation coefficients ranging from 0.76 (for nitrogen and magnesium) to 0.91 (for potassium and phosphorus). Concentrations of these four nutrients were unrelated to calcium with r values ranging from -0.02 to 0.25 (n = 49).

TABLE 3–Correlation between ln stem diameter and ln nutrient concentrations in stem segments (n = 43, r = 0.30, p = 0.05).

Nutrient	Correlation coefficient
Nitrogen	–0.88
Phosphorus	–0.61
Potassium	–0.68
Calcium	0.13
Magnesium	–0.69

Average nutrient concentrations in whole stems were only weakly correlated with dbh with r values of -0.38 to 0.03 (n = 12). Among nutrients, correlations were positive ranging from 0.27 to 0.78 with those among nitrogen, phosphorus, potassium, and magnesium mostly exceeding the 5% significance level.

Detailed sampling of components of the stand revealed a wide range of nutrient concentrations in all tissue types and gave many results outside the ranges reported for

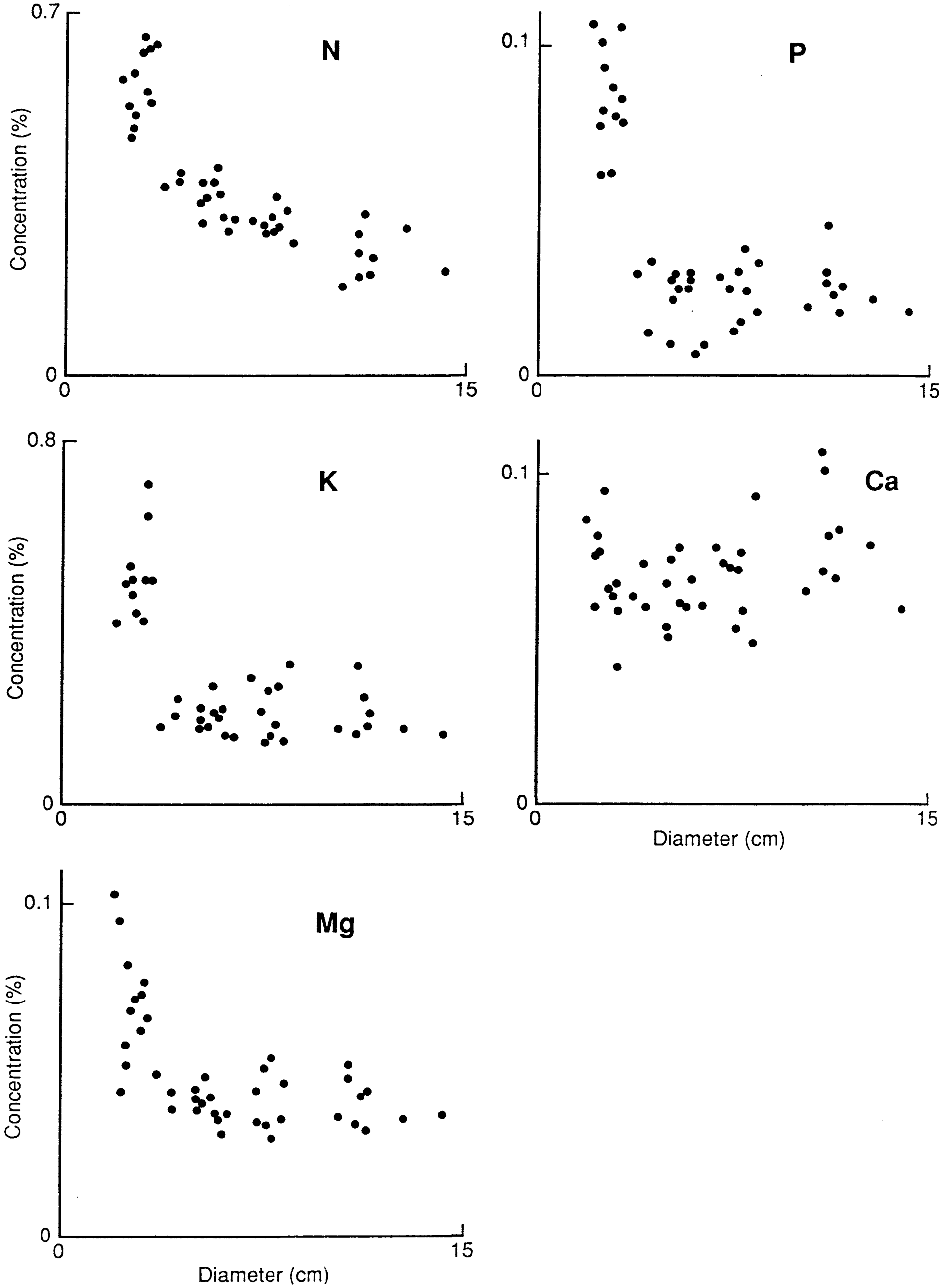

FIG. 4 — Nutrient concentration in stems as related to stem diameter.

P. radiata by Stewart *et al.* (1981). A knowledge of within-tree variability will be used in a later paper to describe changes taking place as a result of fertiliser and thinning treatments.

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