# NITROGEN CONCENTRATION IN FOLIAGE OF PINUS RADIATA AS AFFECTED BY NITROGEN NUTRITION, THINNING, NEEDLE AGE, AND POSITION IN CROWN

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ABSTRACT

Foliar nitrogen concentrations were sampled at four positions on three **Pinus radiata D.** Don trees in each treatment of a 7-year-old replicated thinning × nutrition experiment. Nitrogen concentration decreased with needle age and from top to bottom of the crown, but was unaffected by thinning treatment. In 1-year-old foliage the decrease in foliar nitrogen from top to lower middle of the crown was similar over the range of nitrogen states examined. As needles aged, differences in needle nitrogen among nutritional treatments decreased.

## INTRODUCTION

A knowledge of the factors affecting nutrient concentrations in tree foliage is essential to the development of robust methods for monitoring stand nutrient status. Such knowledge is applicable both to the development of foliar analysis as a guide to fertiliser application and to the prediction of the influence of thinning and live crown pruning on the nitrogen balance of forest ecosystems.

Comprehensive reviews of many studies (Morrison 1974b; van den Driessche 1974) indicate that, from year to year, nitrogen concentration tends to decrease with needle age in evergreen conifers. This trend has been widely confirmed for *P. radiata* (Askew 1937; Will 1957; Hall & Raupach 1963; Kelly & Lambert 1972; Duranti 1974; Florence & Chuong 1974; Mead & Will 1976; Madgwick *et al.* 1977).

Variations in nitrogen concentrations for any one age-class of needles within the crown are less clearcut. A majority of authors, working with a wide range of conifers, have concluded that nitrogen concentrations decrease from top to base of the crown (White 1954; Wright & Will 1958; Swan 1962; Hall & Raupach 1963; Gagnon 1964; Lowry & Avard 1965; Lavender & Carmichael 1966; Raupach *et al.* 1969; Smith *et al.* 1970; Kelly & Lambert 1972; Brazeau & Bernier 1973; Lehtonen 1977). Others concluded that there is no consistent pattern (Will 1957; Peterson 1961; Madgwick 1964; Morrison 1972, 1974a, b). Wells & Metz (1963) found an increase towards the base of the crown while Strebel (1961) found a mid-crown maximum. Closer examination reveals several problems in interpretation. Several of the authors who concluded that

trends do occur have not subjected their data to formal statistical analysis and have sampled few trees. Where formal statistical analysis has been used, trends apparent in some sets of data have been found non-significant. Moreover, it is usually not clear whether within-tree correlations have been taken into account in the statistical analysis of data.

Thinning has been found to increase needle nitrogen concentrations in residual trees (Weetman 1971; Dr R. Gadgil, pers. comm.).

Foliar nutrient levels frequently reflect stand nutritional differences (Morrison 1974b; van den Driessche 1974). The existence of interaction betwen site, needle age, and crown position effects and thinning seems unexplored.

## METHODS

Foliage samples were collected from a comprehensive thinning × nutrition experiment established in a young *P. radiata* forest on a newly stabilised sand dune in Woodhill State Forest north of Auckland (Jackson *et al.* 1983). The experiment consisted of a factorial design of plus and minus fertiliser and plus and minus yellow tree lupin (*Lupinus arboreus* Sims.), with two replicates. The area was planted with marram grass (*Ammophila arenaria* (L.) Link.) in June 1965, topdressed with "Nitromoncal" (granulated lime-ammonium-nitrate mixture) in November, and sown with lupin in the following April. *Pinus radiata* was planted at 2.4 × 1.8 m in June 1968. In December 1968 lupins in the "no-lupin" plots were crushed and sprayed with a mixture of 2,4,5-T and 2,4-D. Fertiliser treatment involved split applications of Magamp, diammonium phosphate, potassium sulphate, dolomite, and urea to supply an average annual addition equivalent to 112 kg N/ha, 47 kg P/ha, 47 kg K/ha, 34 kg Mg/ha, 25 kg S/ha, and 23 kg Ca/ha. Initially fertiliser treatments were confined to equivalent rates around each tree, but after January 1972 broadcast application was adopted.

These main plots were split into four sub-plots with different nominal thinning regimes (Table 1). In 1975, when the foliage samples were collected, the average stockings over all main treatments in the four sub-plots were 790, 1450, 1490, and 2080 stems/ha respectively. Further details of location, site, and management history have been given by Jackson *et al.* (1983).

TABLE 1—Nominal stocking after thinning for each thinning treatment (stems/ha)

| Treatment | Date of thinning | |
|---|---|---|
| | July 1970 | Sept 1972 |
| a | 2224 | 2224 |
| b | 2224 | 1483 |
| c | 2224 | 741 |
| d | 1483 | 1483 |

Three sample trees were selected at random in the treated buffer strip surrounding each measurement sub-plot as part of a comprehensive biomass assessment. One sample branch was selected at random from within each quarter of the crown – viz upper, upper middle, lower middle, and lower crown locations. Each branch was cut close to the stem and all the needles were removed by annual age-classes, irrespective of branchlet order, and dried at 65 °C; a subsample was ground to pass a 1-mm sieve for chemical analysis. Block B (Plots 5–8) was sampled between 18 February and 4 March, starting 1 week after the semi-annual addition of urea; Block A (Plots 1–4) was sampled between 12 and 17 April. The trees were 7 years old at time of sampling.

Nitrogen was determined in each age-class of needles for each sample branch using the indophenol-blue method with an Autoanalyzer after semi-micro Kjeldahl digestion using a selenium catalyst (Faithfull 1971). All determinations were made in duplicate and repeated where duplicates differed more than 1 part in 40 from the mean.

Statistical analyses were based on the mean values for the three sample trees in each plot using analysis of variance for a factorial split plot design. The over-all level of nitrogen concentration would be expected to vary from tree to tree and so the analyses of the effects of crown position and needle age were based on differences between the concentration in 1-year-old needles in the top quarter of the crown and each of the needle age-classes in each of the other crown positions, where sufficient sample material was collected. The nitrogen concentration in the 1-year-old needles in the top quarter of the crown was used as the basis for comparison since this is the sampling position closest to that used for routine diagnostic purposes by the New Zealand Forest Service, though the latter would exclude needles from first-order branches (G. M. Will, pers. comm.). For 1-year-old needles all crown positions were examined, for 2-year-old the lowermost three positions, and for 3-year-old needles the lowest two positions were examined statistically. As the two blocks in the experiment were sampled almost 2 months apart, block and time-of-sampling effects are confounded.

In this paper the notation N(I,J) is used to represent the nitrogen concentration in needles of age I (I ranging from 1 to 3 years) in crown position J where $J = 1$ is the uppermost zone and $J = 4$ is the lowermost zone within the crown.

## RESULTS

Mean N (1,1) ranged from 1.24% in the control plots to 1.46% in the plots with both lupins and fertiliser amendment. Nutritional treatment ($p < 0.05$) and block effects ($p < 0.01$) were statistically significant but neither thinning nor thinning × nutrition interactions were important (Table 2).

For 1-year-old foliage there was a significant decrease in nitrogen concentration with depth in crown (Table 2). Analysis of variance suggested no significant effect of either block or treatment on this trend. For older foliage, block effects and nutritional level both significantly affected the differences in foliar nitrogen between N(1,1) and older needles in other crown positions. Neither thinning nor thinning × nutrition interactions were important. Consequently, average concentrations were determined for all 12 trees in each main plot (i.e., disregarding thinning). These averages for each needle age and crown position are plotted against N(1,1) in Fig. 1 to provide a comprehensive view of the results.

TABLE 2—Summary of statistical analyses of foliar nitrogen concentrations in the 1-year-old needles in the top quarter of the crown (N(1,1)) and the difference between N(1,1) and comparable data for needles in other parts of the crown (N(I,J)) where I is needle age ranging from 1 to 3 years and J is crown position where 2 = upper middle, 3 = lower middle, and 4 = lower crown.

| Variable | Significance of statistical analyses | | | | Mean difference in N concentration (%) |
|---|---|---|---|---|---|
| | Block | Nutrition | Thinning | Nutrition × thinning | |
| N(1,1) | ** | * | NS | NS | — |
| N(1,1) - N(1,2) | NS | NS | NS | NS | 0.06** |
| N(1,1) - N(1,3) | NS | NS | NS | NS | 0.21** |
| N(1,1) - N(1,4) | NS | NS | NS | NS | 0.36** |
| N(1,1) - N(2,2) | ** | * | NS | NS | — |
| N(1,1) - N(2,3) | ** | ** | NS | NS | — |
| N(1,1) - N(2,4) | * | * | NS | NS | — |
| N(1,1) - N(3,3) | ** | * | NS | NS | — |
| N(1,1) - N(3,4) | ** | * | NS | NS | — |

** significant at p = 0.01

* significant at p = 0.05

NS not significant

Examination of each row of graphs in Fig. 1 reveals the oft-reported decrease in foliar nitrogen with needle age. Comparison of each column indicates the decrease in foliar nitrogen down the crown with variation within a zone decreasing with increased needle age. (Note the change in range of the Y-axes used to permit clarity of plotted values.) Where the difference in nitrogen levels btween N(1,1) and N(I,J) is constant irrespective of the absolute nitrogen concentration in N(1,1) the points are scattered around a line at 45° to the X-axis. Such a relationship holds for N(1,2) and N(1,3) but there is a tendency to a flattening of the relationship which becomes significant with N(1,4), as tested using reduced major axis analysis (Liu *et al.* 1966) which takes account of the fact that both variables are measured with error. This flattening is more pronounced for the older needles. Thus, while the difference in N(1,1) between control and fertiliser plus lupin plots was 0.22%, the similar difference for N(3,4) was only 0.07%.

## DISCUSSION

The results support the conclusion that foliar nitrogen in 1-year-old foliage decreases from top to base of the crown of *P. radiata* as found for Australian trees (Hall & Raupach 1963; Kelly & Lambert 1972), but disagree with the data of Will (1957) who

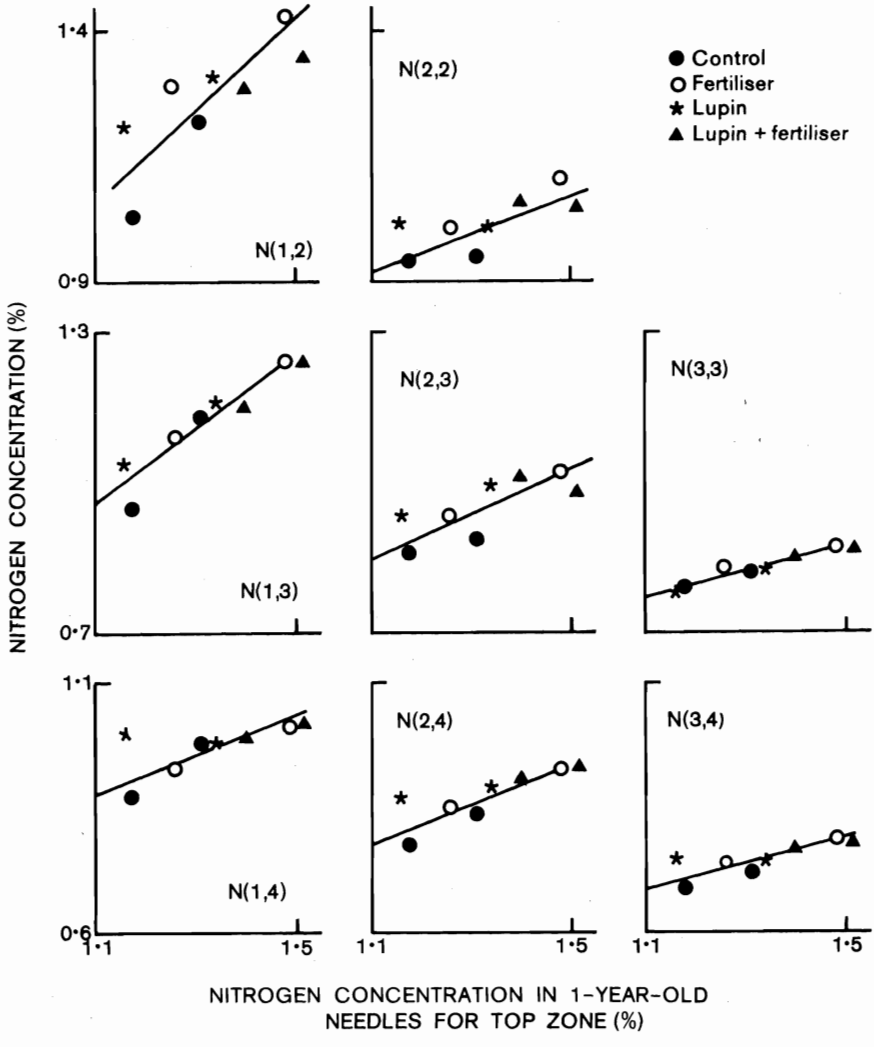


FIG. 1—Mean foliar concentrations of nitrogen for main plots based on 12 trees per plot for each needle age (across page) and each position in crown (Y) plotted against nitrogen concentration in 1-year-old foliage in the upper crown (X). Y-variables are indicated for each graph in the form N(I,J) where I is needle age (years) and J is position in crown where 2 = upper middle, 3 = lower middle, and 4 = lower crown. The slopes for all 2- and 3-year-old needle data are significantly different from 1.0, as is the slope for 1-year-old needles at the base of the crown (i.e., N(1,4)).

found no consistent trend for a small sample of 26-year-old trees in New Zealand. The difference in mean nitrogen in 1-year-old needles between the top and bottom quarter of our trees was 0.36%, which is less than the difference reported by Hall & Raupach

(1963) and Kelly & Lambert (1972), but this is consistent with the much higher absolute values of nitrogen (1.7–1.8%) in the uppermost foliage of their trees compared with 1.1–1.5% in ours.

Our results suggest that the foliar nitrogen concentrations in 1-year-old needles are less variable between treatments at the base of the crown than near the apex. However, this effect is statistically significant only for 1-year-old needles in the lowest zone. This conclusion may reflect the relatively small range in foliage nitrogen in our trees. Raupach *et al.* (1969) found that the difference in foliar nitrogen concentrations between needles at the top and one-third down the crown of *P. radiata* was related to absolute concentrations in the uppermost foliage but their data spanned a much wider range of concentrations than do ours. As needles aged in our experimental area, they tended to a uniform nitrogen concentration related to position in crown but little affected by the absolute nitrogen status of the plot. This decline to an asymptotic level suggests that leakage of nitrogen from older needles, probably from remobilisation within the tree or possibly from leaching by precipitation, is greater in trees of high than of low nitrogen status.

The difference between the two experimental blocks in mean concentration of 1-year-old foliage in the upper crown was 0.16% which was of the same order of magnitude as the range in mean treatment effects, 0.22%. The significant block effects found in several statistical analyses may be explained by the fundamental difference in their foliar nitrogen levels and sampling dates. Routine foliar analyses on samples collected from this experiment at 3-monthly intervals over a number of years have tended to indicate that Block A (Plots 1–4) has lower foliar nitrogen concentration than Block B (Dr R. Gadgil, pers. comm.). Independent statistical analyses of each collection have indicated significant differences between the blocks on two separate occasions, one of which was in August of the year of our sample collection. Mead & Will (1976) included samples from Woodhill in their studies of seasonal changes in foliar nutrients in *P. radiata* needles and for that forest found a rise in foliar nitrogen concentration in "young" foliage and declines in "older" foliage during the late summer. Our results will also have been affected by the timing of the semi-annual urea fertiliser application which was carried out 1 week before we sampled Block B. As Block A was sampled in mid-April almost 2 months after sampling Block B, any changes in foliar nitrogen concentrations over this period would have influenced our results.

We found no significant effect of thinning on foliar nitrogen levels based on three sample trees per plot. This result contrasts with other work in the same experimental plots where standard foliage sampling based on 8–10 trees per plot indicated that thinning effects are present (Dr R. Gadgil, pers. comm.). We conclude that failure of our data to indicate thinning effects reflects the lower number of trees sampled.

Most authorities recommend sampling for diagnostic purposes from 1-year-old foliage in the upper crown (Morrison 1974b). While our results suggest that wide differences in thinning do not affect foliar nitrogen concentrations, they do confirm that the relative differences among nutritional treatments are greatest for young foliage in the upper crown. However, the correlations between current basal area increment, total stand basal area, and total height (Jackson *et al.* 1983) and foliar nitrogen were higher for 2-year-old foliage in the upper mid-crown ($r = 0.78$, 0.76, and 0.50, respectively)

than for 1-year-old foliage in the upper crown (r = 0.42, 0.48, and 0.27). Current height increment was most closely correlated with foliar nitrogen in 1-year foliage in the upper-mid crown (r = 0.69). It would appear that the widespread convention of sampling 1-year-old foliage from the upper crown for diagnostic purposes is founded on one primary source (Leyton & Armson 1955) and that the validity of this convention should be more fully tested.

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