EVALUATING THE NUTRITIONAL STATUS OF FRASER FIR [ABIES FRASERI (PURSH) POIR.] CHRISTMAS TREES USING FOLIAR ANALYSIS AND DRIS APPLICATION

by

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(ABSTRACT)

Three studies were conducted with Fraser fir Christmas trees to determine the variation in foliar nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) levels among plantation ages, sample locations within the crown, and effects due to seasonal changes. Extensive variation in nutrient concentrations existed with age of tissue collected, sample location with respect to aspect and vertical position, and normal seasonal fluctuation. Tree to tree nutrient variation indicated that greater sampling intensities are required for younger (under four years) plantations as opposed to older (over four years) plantations to achieve comparable confidence and precision levels. The data clearly illustrated that comparisons of foliar nutrient levels without regard to these sampling variables could cause erroneous diagnoses. Recommended foliar sampling practices involved sampling current-year's tissue from 2- or 3-year-old south-facing branches in October or November for routine foliar diagnoses.

Another study developed a DRIS application to evaluate N, P, K, Ca, and Mg nutrition on seventy-nine trees in a 3-year-old Fraser fir Christmas tree plantation. DRIS norms and index equations from premium grade Christmas tree were developed. In contrast to most crops where growth and yield are assessed, Fraser fir Christmas tree performance was evaluated by conventional grading procedures based on tree quality. A classification model utilizing several measured growth characteristics to predict Christmas tree grade was also investigated to objectively evaluate tree performance. Satisfactory grade-prediction results using a discriminant model were obtained yielding overall correct classification rates of 80 percent. Preliminary evaluation of DRIS performance suggested that assessments of nutritional balance, rather than examination of individual nutrient concentrations, may be more useful for prescribing fertilizer to improve Christmas tree quality.

DEDICATION

To

my future wife, Kimberly Kearns

and my family

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INTRODUCTION

Fraser fir [*Abies fraseri* (Pursh) Poir.] has become one of the most prized Christmas tree species in the East and is the most frequently planted Christmas tree in North Carolina. High consumer appeal and recently expanded markets have made large-scale Fraser fir Christmas tree production a potentially profitable venture. The production of quality trees, however, is management intensive and requires cultural treatments such as fertilization, vegetation and pest control, and shearing.

Christmas tree quality is a function of many growth characteristics including crown density, needle length, needle retention, color, and fragrance. Tree quality is obtained through an optimization of all these factors. Inadequate levels in any of these attributes, such as chlorotic foliage or a sparse crown, will result in reduced quality and consequently decreased salability. Marginal or poor quality trees can result from nutrient deficiencies or imbalances. Some nutritional problems which have reportedly been found with Fraser fir are chlorosis (insufficient nitrogen (N) and/or magnesium (Mg)), poor bud development (insufficient phosphorus (P)), and needle drop (insufficient calcium (Ca)).

Optimum tree nutrition should be maintained by implementing a well-designed fertilization program. Such a program should be based on an understanding of tree nutrition and its relationship to tree quality. Diagnostic techniques need to be developed to assess nutrient needs and make effective fertilization prescriptions.

Foliar chemical analysis has been used by agronomists for years to diagnose crop nutrient needs. The value of this tool is enhanced when tissue is sampled according to standardized methods. For many crops, guidelines have been developed on how, when, and where to sample individual plants. Comparisons of established standards to diagnose foliar levels should logically be made with tissue sampled from the same plant part, growth phase, stage of maturity, and time of year. Interpretations of foliar nutrient data biased by incorrect sampling procedures are difficult and misleading. With respect to conifers, little is known about sample nutrient variation. Investigation of sample variation in Fraser fir foliage at different crown positions, tissue ages, and times of year is needed in order to standardize sampling techniques for reliable interpretation.

Several diagnostic schemes have been used in conjunction with chemical tissue analysis. One which appears to be suited to Fraser fir Christmas trees is the Diagnosis and Recommendation Integrated System (DRIS) (Beaufils, 1973). DRIS is a diagnostic method which has been used by agronomists for more than ten years to improve yields from rubber plants, sugarcane, corn, and other crops. The DRIS approach has applications whenever one or more nutrients may be limiting and when nutrient imbalances affect crop response. A premium-quality Christmas tree would presumably have desirable levels of all nutrients and any deviation from this "optimum" could result in lower tree grade. The application of the DRIS system, which utilizes sets of established nutrient-level ratios (DRIS "norms"), could be useful in detecting these suboptimal conditions. Once DRIS norms have been established and successfully tested in relation to tree quality, the procedure can be applied to increase fertilization efficiency and enhance tree quality.

The purpose of this study was to standardize Fraser fir tissue sampling for nutrient analysis and to evaluate DRIS as a diagnostic and prescription tool for making fertilizer recommendations for Fraser fir plantations. Specific objectives for each of the individual studies are listed below.

Within Plantation Variation Study

1. To investigate the inherent variation in nutrient concentrations in Fraser fir foliage within a plantation on a homogeneous site.
2. To determine sample size requirements for adequately evaluating a Fraser fir Christmas tree plantation.

Within Tree Variation Study

1. To investigate the variation in nutrient levels within Fraser fir Christmas trees as affected by needle age, cardinal location, and vertical position on the crown.
2. To establish the most desirable location for standard diagnostic foliar sampling in Fraser fir Christmas trees.

Seasonal Variation Study

1. To examine the annual fluctuations in nutrient levels of current and previous-year Fraser fir foliage in plantations of different age.
2. To determine the best time of year to sample Fraser fir foliage for diagnostic purposes.

DRIS Study

1. To investigate the relationships between Fraser fir growth

characteristics and Christmas tree grade.

2. To develop a discriminant model that classifies individual trees into one of the grade categories based on measured tree attributes.
3. To establish a provisional set of DRIS norms and equations for premium grade Fraser fir Christmas trees using foliar nutrient levels.
4. To perform a preliminary evaluation of DRIS performance on the Christmas tree data set.

LITERATURE REVIEW

Within-Plantation Variation Study

Investigations in the tree to tree or within-plantation variation are needed before sampling intensities required to obtain estimates of foliar variables of a given precision can be determined. The precision with which the mean value of any foliar nutrient must be estimated, however, will depend on the objective of the investigation. Less precision is needed to determine whether a deficiency exists, compared to that required for estimating quantitative responses to fertilizer.

Levels of precision and confidence in estimation are a function of two parameters in sample size calculations. The first and probably most important is the acceptable error or deviation tolerance which is normally specified as plus or minus a percentage of a sample mean in absolute terms. The second is the alpha level, which is the risk that the actual error is greater than the allowable error, or the probability of a type I error. Reported acceptable error and alpha levels for conifers range from plus or minus 1.25 to 20% of the mean and 0.001 to 0.20, respectively (Berglund et al., 1976; Knight, 1978; Mead and Pritchett, 1974; Mead and Will, 1976; Proebsting and Chaplin, 1983). However, for most diagnostic applications in conifer stands van den Driessche (1974:377) stated, "It seems rather likely that, for practical reasons, it will only be possible to sample sufficiently heavily to detect differences which are at least 10% of the mean." In contrast to conifer stands managed for timber, collection of foliage samples in most Christmas tree plantations is relatively easy and convenient.

Consequently, larger sample sizes for reduced error and greater confidence may be justified. Furthermore, increased sampling intensity need not increase chemical analysis work since all samples from a given "homogeneous" site may be analyzed as a composite sample.

Besides obvious site differences, factors which have been observed to affect tree-to-tree variation of foliar variables in a conifer stand or plantation are the degree of dominance in trees sampled, the sampling period, the nutrient(s) of interest, and the sampling location within the crown. Although lower nutrient variation within a stand of Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco var. menziesii] has been observed for individual trees with greater expression of dominance (Lavender, 1970), this effect is probably not important in Christmas tree plantations.

Few studies have examined the effect of sampling date on within-plantation nutrient variation, and those that have showed weak evidence for any trend which is usually nutrient-type and tissue-age dependent. Current-year's tissue in young Monterey pine (Pinus radiata D. Don) plantations demonstrated significantly lower variation of K in winter as opposed to summer-collected samples, while a reverse tendency was observed for N and P (Mead and Will, 1976). Potassium concentrations in slash pine (Pinus elliottii Engelm. var. elliottii) foliage also showed lower variation in December-collected samples than in June, whereas an apparent reverse trend was evident for Ca (Mead and Pritchett, 1974).

The majority of evidence suggests that the particular nutrient of interest has the most noticeable affect on within-plantation variation. Virtually all studies which have involved tree to tree foliar nutrient variation have noted variability differences for each nutrient. For purposes of this review, however, only variation reported on the five nutrients (N, P, potassium (K), Ca, and Mg) of interest in this study were noted. The general nutrient trends on this form of variability agree reasonably well among species, yet the specific effects tend to differ with tissue age and crown position.

Calculated sample-size requirements for estimating N, P, K, Ca, and Mg levels at acceptable errors of 10% of the mean and alpha levels of 0.05 in 35-year-old red pine (Pinus resinosa Ait.) were 6, 8, 22, 30, and 14 trees, respectively (Berglund et al., 1976). Similarly, White and Jokela (1979) determined sampling intensities of 3, 9, 10, 13, and 9 trees for the same nutrients in a 40-year-old red pine plantation. Mean coefficients of variation on current tissue collected from 11 whorl ages on a 49-year-old red pine stand were 4.6 (%), 9.0, 32.1 for N, P, and K, respectively (Comerford, 1981). Hence, for this species, there appears to be a trend of increasing variability for nutrients in the order N, P, Mg, K, and Ca, and consequently a standard sampling intensity would tend to estimate these nutrients with decreasing levels of precision in that order.

Comparable effects and nutrient ordering have been observed with other species. Mead and Will (1976) calculated sample size requirements of 4, 11, 14, 35, and 24 for N, P, K, Ca, and Mg, respectively, with error tolerances of plus or minus 10% of the mean and standard ($P \leq 0.05$) confidence limits for young monterey pine plantations on a range of sites throughout New Zealand. Required sampling intensities with similar precision in young Douglas-fir Christmas tree plantations were estimated to be 5, 9, 19, 19, and 23 for the same five nutrient elements, respectively (Proebsting and Chaplin, 1983). Also, parallel estimates of 2, 7, 26, 32, and 18 on the aforementioned nutrients were computed for 11-year-old slash pine in northern Florida (Mead and Pritchett, 1974).

A summary of their findings indicates that N variability is least, about two and three times the samples required to estimate P and K levels with the same precision, and generally the greatest sampling intensity is required for Mg and Ca. In practice, depending on resource constraints, multiple element estimates from one composite sample are obtained by specifying sampling requirements based on the most variable nutrient or by compromising on the precision level of the less important nutrients.

Tree to tree variation may also differ according to the sampling location on the tree with respect to tissue age and vertical position in the crown. In general, samples collected during the dormant season tend to have lower variability in current foliage compared to previous year's foliage for most of the macronutrients. Working with 11-year-old slash pine, Mead and Pritchett (1974) noted this effect for N, K, and Mg. Results with young monterey pine indicated 5, 34, 117, 28, and 6 percent greater variation in N, P, K, Mg, and Ca, respectively, for previous as opposed to current year's foliage (Mead and Will, 1976). Reporting on the same species in another study, Mead (1984) showed increasing variation for N, P, and Ca with increasing tissue age for middle and lower crown positions except for Ca which had a reverse trend at the lowest crown height. He also found declining variation with lower crown positions for P in currents year's needles, whereas, the opposite was apparent for N. In a foliar nutrient characterization study of mature red pine, the same trend of lower variability for current versus 1-year-old tissue in upper crown positions was found for N and P, while the converse was true for K (Comerford, 1981). Comparing the effect of vertical sampling position in the same species, White and Jokela (1980) found greater sampling intensities required for bottom versus top crown positions for N, P, Mg, and Ca, whereas, the reverse occurred for K.

In summary, there are several factors which have been observed to affect tree to tree nutrient variation. Even though consistent trends and exceptions were noted with each factor, it is important to keep their effects and interactions in mind when standardizing foliar sampling conditions for Fraser fir Christmas trees. Ideally, a sampling period and sampling location could be chosen that would minimize variation for all nutrients of interest. However, a standard sampling condition usually involves compromises with respect to every factor. Additionally, reducing tree-to-tree variation is only one of several important criteria which should be used in standardizing sampling techniques.

Within-Tree Variation Study

Standardization of foliar sampling techniques on a new species for diagnostic purposes should only be completed after nutrient variation as affected by sampling location within the tree has been investigated. Additionally, an assessment of the diagnostic value for various locations is needed to determine the best standard position. Three factors that may affect observed nutrient status in conifers are: 1) aspect or cardinal direction; 2) tissue age; and 3) vertical position of sampled tissue.

Few studies have examined the effects due to aspect or cardinal location on the crown nutrient levels because of its suspected minor influence. Its greatest effect would probably occur on species with exceptionally dense crowns and at higher latitudes where differential shading is most important. Many workers have restricted their sampling to a particular aspect (e.g., Leyton and Armson, 1955; Wells and Metz, 1963; Wells, 1965; Lavender and Carmichael, 1966; White and Jokela, 1980) presumably to avoid confounding other effects with possible aspect differences. Others have largely ignored possible aspect differences, referring to works like White (1954) who observed no significant differences in K between north, east, south, and west-facing samples for red and white pine (Pinus strobus L.). However, his results involved analysis of K on only four trees of each species in a 12-year-old plantation which had not yet closed canopy. The plantation was located on potash deficient soils. Analyses of other non-deficient elements in a well stocked stand of these species with closed canopy may have revealed some differences due to aspect. In contrast, sheared Fraser fir Christmas trees can have very dense crowns, and nutrient-level changes due to aspect (especially north versus south) may occur. Information concerning the prevalence of such effects would be useful for standardizing sample locations in Fraser fir.

Nutrient level differences between varying tissue or needle ages have often been noted, yet the current season's foliage has been generally accepted as the most useful for diagnostic purposes (Leaf, 1973). Reasons for this preference include the higher correlations between nutrient concentration and shoot length (Leyton and Armson, 1955), site index (Lowry and Avard, 1969), and availability of soil nutrients (Lavender and Carmichael, 1966). In addition, attention is often focused on the N status of the tree, and current season's foliage is usually the most sensitive indicator of this. On the other hand, it has been suggested that the most suitable foliage age to sample depends on the nutrients to be studied (Wells and Metz, 1963). In loblolly pine (*Pinus taeda* L.) current needles discriminated best for P and K differences between sites, but 1-year-old needles were most discriminating for Ca and Mg. There are many factors that should be considered in the choice of needle age, and delineation based on the tissue age with greatest site differences for a given nutrient is only one of them. The phenological age with greatest temporal stability that best reflects the current nutrient status of the tree (reviewed in a later section) are other primary considerations. There are obvious practical advantages to obtaining nutrient level estimates on one tissue sample in terms of minimized sampling and analytical work and the number of comparative standards needed. Moreover, advanced diagnostic systems, like DRIS, generally require multiple element estimates on one tissue sample for assessing the magnitude and nature of nutrient imbalances (Beaufils, 1973).

For most conifers, young foliage usually has higher concentrations of the more mobile elements (N, P, K, and to some extent Mg) than older foliage, while the least mobile elements (Ca, and some of the micronutrients) tend to have a reverse trend (Leyton and Armson, 1955; Madgwick, 1964; Lowry and Avard, 1969; Mead and Will, 1976). Exceptions have been observed for P in Douglas-fir (Lavender and Carmichael, 1966) and slash pine (Mead and Pritchett, 1974) and for N in red pine (Comerford, 1981).

Many researchers have demonstrated nutrient-level differences depending on the vertical sampling position within the tree crown. Van den Driessche (1974) reviewed this effect and identified five basic mineral nutrient distributions within tree crowns. Type I, II, or III distributions correspond to situations where nutrient levels remain constant (I), generally increase (II), or generally decrease (III) with increasing crown heights. Types IV and V are special cases where maximum and minimum levels, respectively, are found at mid-crown positions and highest and lowest crown heights have approximately the same concentrations. While nutrient concentration distribution patterns may well be species dependent (van den Driessche, 1974), it is also possible that the extent of crown closure (White, 1954), the degree of stand or tree vigor (Madgwick, 1964; Swan, 1962), and differences in nutrient availability (Hall and Raupach, 1963) may modify the normal patterns found. Additionally, the pattern for a particular nutrient may change for different foliage ages.

Current-year's foliage results with Scotch pine (Pinus sylvestris L.) (Leyton and Armson, 1955; Wright and Will, 1958), white pine (White, 1954), red pine (White, 1954; Comerford, 1981), loblolly pine (Wells and Metz, 1963; Smith et al., 1970), and Monterey pine (Hall and Raupach, 1963; Mead, 1984) indicates that distribution type II, type II, and types II and III are the most commonly observed with N, P, and K, respectively. Reported exceptions are a type I in red pine (Madgwick, 1964) and monterey pine (Will, 1957) and type III in loblolly pine (Wells and Metz, 1963) for N, a type V in red pine (Madgwick, 1964; Comerford, 1981) and type III in Monterey pine (Will, 1957) for P, and a type V in red pine (Madgwick, 1964) for K. For the same species, Ca and Mg tend to fall in the type III, and type II categories, respectively. However, Wright and Will (1958) indicated a type II Ca pattern for Scotch pine and Madgwick (1964) found a type IV Ca pattern with red pine. Also, a type I and III Mg distribution was identified with monterey pine (Will, 1957) and loblolly pine (Wells and Metz, 1963), respectively. Similarly, a type II pattern has been observed for N and Mg in black spruce (Picea mariana (Mill.) B. S. P.) (Gagnon, 1964; Lowry and Avard, 1965). Lavender and Carmichael's (1966) results with Douglas-fir also demonstrated the common trends of type II distributions for N, P, K, and Mg and a type III for Ca. While similar distribution trends for each nutrient element are evident, dissimilar findings may be attributed to one or more of the modifying factors mentioned earlier.

Most workers agree that upper crown sampling is best for diagnostic purposes, yet some have proposed lower (Madgwick, 1964) and midcrown (White, 1954) sampling heights. Van den Driessche (1974:353) stated, "In practice the sample should be that which has most predictive value for the objective of the study, whether this is response to fertilizer, or prediction of some growth parameter. The most satisfactory crown region to provide this sample can probably only be determined by extensive sampling trials, and it does not seem desirable to confine attention to the upper crown." What appears to be most important is that once calibrations have been made on a particular crown position, tissue age, aspect, etc., future diagnostic samples should meet those criteria or the interpretation could be incorrect.

Seasonal Variation Study

Standardized foliar sampling schemes usually have restricted tissue-collection periods because of the large seasonal variation in nutrient levels (Leaf, 1973; van den Driessche, 1974). The relative size of this source of variability for the five nutrients is indicated in Knight's study (1978) where the fraction of total variation accounted for by sampling date ranged from 0.68 (N) to 0.22 (K). Hence, it is evident that reducing this form of variability by identifying the best sampling "window" will enhance the diagnostic power of tissue analysis.

For most species, seasonal trends differ markedly between nutrients with the more mobile elements (N, P, K) tending to show early summer peaks tapering off by autumn while less mobile elements like Ca tend to acumulate throughout the growing season. These general trends for N, P, and K have been observed for slash pine (Mead and Pritchett, 1974), loblolly pine (Wells and Metz, 1963), red pine (White, 1954), jack pine (Pinus banksiana Lamb.) (Morrow and Timmer, 1981), Monterey pine (Mead and Will, 1976), and Douglas-fir (Proebsting and Chapling, 1983). The non-mobile behavior of Ca described above has been invariably reported with the species mentioned, except in the case of jack and red pine where Ca analyses were not reported. In addition, seasonal data carried on through the first dormant season generally indicates minor secondary peaks in N and P concentrations during late autumn to early winter followed by a decline until the beginning of the next growing season (White, 1954; Wells and Metz, 1963; Miller, 1966; Mead and Pritchett, 1974; Knight, 1978; Proebsting and Chaplin, 1983). In one investigation on Monterey pine, however, N levels gradually increased from needle initiation until late winter (Mead and Will, 1976). Seasonal fluctuations in Mg tend to indicate an intermediate behavior in mobility with evident characteristics of translocation and accumulation (Wells and Metz, 1963; Mead and Pritchett, 1974; Knight, 1978; Proebsting and Chaplin, 1983).

Requirements for a standard foliar sampling period for diagnostic purposes appears to involve two basic criteria. First, it is highly desirable to designate a sampling "window" during which changes in foliar nutrient levels are minimal. Second, a standard sampling period should be chosen that best reflects the plantation nutrient status or when site and/or treatment differences are readily detected.

Greatest nutrient level stability has generally been found in autumn and winter, hence, this has been the period most often favored for sampling in temperate and cool climates (Gessel, 1962; Lavender, 1970; Waring and Youngberg, 1972; Leaf, 1973). Low physiological activity during the dormant season is generally thought to be the cause for reduced nutrient fluctuations (van den Driessche, 1974). Working with loblolly pine in central Mississippi, Miller (1966) noted considerable variation in foliar N, P, and K concentrations during the autumn and winter months when he compared his results with those of an earlier study on red pine (White, 1954). He attributed this greater variation to the indeterminant growth habit of loblolly pine. His results were confounded by the sampling scheme which involved monthly collection of tissue from the most recent growth flush as long as the needles were at least 4.3 cm long. Another possible factor that was not discussed is the length and extent of dormancy for loblolly pine in Mississippi compared to red pine in New York. Certainly, greater physiological activity occurs for related species during the dormant season in Mississippi than in New York, which should be reflected in the magnitude of nutrient fluctuation. Overall, a comparison of his growing season versus dormant season nutrient variation results indicates considerable dormant season stability.

The optimal sampling period for greatest sensitivity to site differences has been somewhat controversial and there are indications that this period may vary according to the particular nutrient. With dormant season sampling, the underlying philosophy seems to be that the plant internal nutrient concentrations equilibrate with soil nutrients, and so an indication of nutrient availability to the plant is obtained. More recently, this concept has received less support. It was pointed out by Leaf (1973:437) that "The biological justification for an autumnal collection time for foliage is questionable. It is a time following translocation of the mobile nutrient elements out of the foliage in preparation for next season's growth, and a time following deposition of the nonmobile elements. Thus, analysis of foliage at this time does not measure nutrient element levels during their physiologically important use period." A better reflection of the nutrient status may be obtained by sampling at the period of maximum "nutrient stress", when extension growth is complete (van den Driessche, 1974).

Several workers have isolated different periods as being best for interpretation of different nutrients. Greater sensitivity in detecting site differences for jack pine was found for N, P, and K sampled during the growing season, and Ca and Mg during the winter (Lowry and Avard, 1969). For Monterey pine, between-site differences in N and Mg were delineated better for summer-collected tissue, while autumn collections were better for K (Mead and Will, 1976). They also noted that summer through autumn would have been equally sensitive for P, and autumn collections of previous year's needles were most suitable for Ca.

Establishing different sampling periods for different nutrients seems feasible for comparing the nutrient status of plantations on diverse sites; however, such an approach appears disadvantageous for standardization purposes. Even with narrow sampling "windows" during the growing season, interpretations of standard comparisons across vastly different sites may be affected by differences in foliar phenology. Such an affect could be quite significant even for the range of sites and elevation which support Fraser fir Christmas trees. In addition, multiple collections, analyses, and standard comparisons would be required annually for routine monitoring purposes. Also, such an approach would be suitable to a critical or sufficiency level diagnosis and not to a more comprehensive multi-element evaluation, such as that employed by DRIS. Thus, a single standard sampling period appears desirable, even though minor sensitivity for one or more nutrients may be sacrificed.

In summary, the general seasonal trends of mobile versus non-mobile nutrient levels differ for all conifer species reported due to the varying extent of translocation or accumulation occurring throughout the growing season. Standardization of a sampling period should consider the temporal stability in all nutrients of interest at least for the duration required to complete a sampling program. Attention should also be given to identifying periods of greatest sensitivity to nutritional differences between sites. Practical implications of a single, broad sampling window for Fraser fir Christmas trees appear important when considering the potentially diverse clientele.

DRIS Study

While several diagnostic techniques are used in conjunction with chemical tissue analysis, the DRIS approach appears to be the most promising for use with Christmas tree quality evaluation. DRIS provides greater diagnostic precision and flexibility than use of critical levels (Sumner, 1979). The relatively short rotation age of Christmas trees (compared to timber production) also seems to make it ideally suited to DRIS for monitoring crop nutrition. Additionally, the apparent flexibility of DRIS in adapting to any of the important Christmas tree quality determinants (e.g., needle length, bud or leader density, etc.) as a performance variable, could be an attractive feature for "fine-tuning" diagnoses.

The DRIS methodology, formerly called "Physiological Diagnosis", was originally developed by Beaufils (1971) to increase latex yields from rubber trees (Hevea brasiliensis Muhl. Arg.) in Vietnam. Since then, successful applications to corn (Zea mays L.), soybeans (Glycine max

L.), wheat (*Triticum aestivum* L.), coastal bermudagrass (*Cynodon dactylon* sp.), potatoes (*Solanum tuberosum* L.), sugarcane (*Saccharum officinarum* L.), and hybrid poplar (*Populus deltoides* Marsh.) have been made (Elwali and Gascho, 1983; Escano et al., 1981a; 1981b; Gascho and Elwali, 1979; Jones and Bowen, 1981; Kelling et al., 1981; Leech and Kim, 1981; Meldal-Johnsen and Sumner, 1980; Sumner and Beaufils, 1977; Sumner, 1977a; 1977b; 1977c; 1977d; 1978; 1979; 1981; Tarpley et al., 1985). Accurate diagnoses of nutrient imbalances and corrective treatments for improved crop yield or quality has been demonstrated for a variety of species.

Fundamentally, DRIS represents a comprehensive, non-specific experimentation approach capable of calibrating any quantifiable yield or quality factor in the soil/plant/environment system (Beaufils, 1971). For purposes of this review, only basic concepts and assumptions for the plant calibration system will be discussed. Specific experimentation techniques and mechanics of the methodology are outlined in detail in Beaufils' monograph (1973).

Reduced to its simplest form, the plant calibration system involves the development of DRIS norms from a survey of a particular crop in which standardized tissue collections and associated yield or growth performance are recorded. It is important that this survey be composed of a sufficiently large randomized sample which is representative of the range and distribution of quality or yield in the population at large (Beaufils, 1973). Tissue nutrient levels are then expressed in as many combinations of forms as possible (e.g., nutrient concentration as % dry matter, nutrient concentration ratios, nutrient products, etc.). The whole population (or sample) is divided into two or three subpopulations (e.g., high, medium, low yield) for which means and variances of each nutrient expression are calculated. A Chi-square test for conformation to normality is generally performed on each expression in the populations followed by an F-test on variances between populations. Only forms of expression with significantly greater variances in the poor or undesirable population are retained as discriminatory norms. However, proposed modifications to DRIS include use of significantly different mean expressions in DRIS index equations (Jones, 1981). Finally, nutrient index equations are developed by combining every discriminant expression containing the nutrient of interest into functions of the appropriate form (Beaufils, 1973). This completes the establishment of provisional DRIS index equations, yet, it only concludes one of many stages required prior to operational use of the system. Subsequent stages include rigorous testing and validation of norms in diagnosis on fertilizer trials and operationally through verified responses to prescribed corrective treatments. Continual data base expansion and norm refinement is needed to improve utility and confidence in the system.

Several assumptions concerning the way in which the nutrient status of the tissue affects crop yield/quality are inherent with the DRIS technique (Beaufils, 1971; 1973). A brief summary of these assumptions is given below.

1. Ratios of nutrient element concentrations are often better indicators of nutrient deficiencies than are single nutrient element levels.

2. Some of these ratios are more important than others.
3. Maximum crop yield/quality are attainable only when the values of important ratios approach an optimum value, which is approximately the mean value of the ratio in a selected high yielding (or otherwise desirable) population.
4. Since important ratios must approach their optimum values to obtain high yields/quality, the variance of important ratios is smaller for high versus low-yielding populations. The ratio of the variances of low to high-yielding/quality populations can be used to select important ratios.
5. A DRIS index can be calculated for each nutrient element that is based on the mean deviation of each important ratio (in which that nutrient element is either a numerator or denominator) from its optimum value. Thus, the optimum DRIS index for any nutrient element is 0.0, and negative indices indicate deficiency, while positive indices indicate sufficiency.

Therefore, use and interpretation of DRIS indices is ultimately based on these fundamental assumptions.

Only two documented applications of the DRIS methodology with foliar nutrients to commercially important tree species are available. Hybrid poplar growth and nutrient status in both field plantations and greenhouse environments were related to DRIS indices in Canada (Leech and Kim, 1981). In this study, index validity was established through monitoring seasonal index changes in response to successive operational fertilizer applications. Noted important features of the fertilizer response were the nutrient interactions and sensitivity of DRIS in indicating limiting nutrients. Although the study only employed a small part of the DRIS methodology, the workers remarked at the usefulness observed in detecting nutrient limitations and guiding fertilizer prescriptions. A preliminary investigation with monterey pine to evaluate N, P, and sulfur (S) relationships via DRIS techniques has also been reported (Truman and Lambert, 1981). No diagnostic validations were investigated; yet, comparison of sample DRIS indices did support earlier reports of enhanced P nutrition due to ash-bed effects. The merits of the system, especially with fertilizer selection, were noted in this investigation.

METHODS AND ANALYSIS

Background Information

The study site, owned by the H. Smith Richardson Charitable Trust, is located on Bald Mountain in Watauga County, North Carolina. Plantations were established in 1977, 1980, 1981, 1982, 1983, and 1984. Rotations of about 7 to 8 years are required after planting 3-2 stock (trees grown 3 and 2 years in seed and transplant beds, respectively).

Soils of these grassy balds, where most of the plantations have been located, are extremely variable depending primarily on topography and differences in parent material. Typically, the soils are formed from residuum or colluvium, predominantly composed of high grade metamorphic rocks, such as mica gneisses, mica schists, granite gneisses, and phyllite. Extremes in topography, with respect to slope, aspect, and landform tend to have a marked influence on soil depth, drainage, and other physical properties important to Fraser fir growth.

Plantations are located on the Ashe (coarse-loamy, mixed, mesic, Typic Dystrochrept) and Watauga (fine-loamy, mixed, mesic, Typic Hapludult) soil series with some areas situated on soils weathered from stony colluvium with parent materials of both the Ashe and Porter series. Characteristic soils typically have thick A horizons (greater than 20 cm) with high organic matter contents (10 to 12 %). This is an expression of the grassland culture which has been maintained on these balds for many years. Coarse fragments, from gravel to boulder sizes, are also a common occurrence throughout the soil profiles. Despite some of these physical limitations, the inherent fertility of these sites is moderate to high.

The studies reported are part of a larger research project initiated during the summer of 1983 to investigate the site and nutrient requirements of Fraser fir Christmas trees.

Beginning phases of the project focused on several studies intended to provide an understanding of Fraser fir foliar nutrient characteristics. In addition to the four studies outlined, three other concurrent studies were initiated. The objective of a translocation study was to determine if nutrient concentrations were affected for needles stripped from shoots in the laboratory some time after field collection as compared to field-stripped and bagged needles. Results from this study indicated no significant ($P \leq 0.05$) differences in N, P, K, Ca, and Mg concentrations for the two tissue sampling methods.

A plantation characterization study was established to ascertain the growth and nutritional status of eight different areas within two plantation ages. The eight sample units were differentiated on the basis of aspect, slope, drainage, and past management practices. Composite soil and tissue samples from 20 trees within each unit along with detailed growth, color, and bud development information on each tree were collected during the Fall of 1983. When completed, the results of this study will be used to infer relationships between foliar levels, growth characteristics, soil chemistry, and landscape positions.

Another major project initiated during the Spring of 1984 was the installation of a fertilization trial in a newly established (1984) plantation. The trial, which includes three separate studies each based on a factorial design, examines the following factors: nutrient element

(N and P), application rate (three levels each), timing or frequency of applications (two levels), nutrient sources (conventional and slow release), and soil reaction (three pH levels). Three replications of the trial on two different soil types, each established with adequate controls, will yield valuable information on the response of Fraser fir to the different treatment combinations. Additionally, the fertilizer trial will serve a primary role in validation and calibration efforts to refine the DRIS application.

Within-Plantation Variation Study

Foliage samples from 20 trees were taken from plantations established in 1977, 1980, and 1982. Areas of about 0.4 ha for each plantation were selected to minimize slope and aspect differences. Approximately 5 g (fresh weight) of current- and previous-year's needles were collected from each randomly-located tree. Sample locations were restricted to the 2- and 3-year-old primordial branches on the south side of the tree crown. Tissue samples were bagged in the field and kept under refrigeration until they could be dried in the lab. Tissue handling, preparation, and chemical analysis techniques, which were identical for all four studies, are described in a later section.

All data analyses for the four studies were performed with the Statistical Analysis System (SAS). Means and variances for each of the five nutrient concentrations were determined for each plantation. Coefficients of variation were examined and necessary sample sizes computed. Comparisons of different sampling intensity requirements based on changes in error tolerances were made to identify practical precision constraints. Differences in variability among nutrients, foliage and plantation ages were investigated using one-way analysis of variance (ANOVA).

Within-Tree Variation Study

Tissue samples from 10 randomly located trees in an 7-year-old plantation were collected in November, 1983. From each tree, samples were removed from a total of 24 sampling locations differentiated by cardinal direction (north and south), primordial branch or whorl age (1-year, 2-year, 3-year, 4-year, and 5-year-old whorls), and foliage age (current, 2-year, and 3-year-old needles). Thus, for each side of the tree (north or south) 12 samples were obtained with five crown heights and three tissue ages represented. Trees selected covered the range in site differences represented in the 7-year-old plantation with regard to topographic variation.

Differences in nutrient concentration due to aspect, crown height, and tissue age were examined. ANOVA and multiple comparison procedures were applied where appropriate to isolate these differences. Graphical plotting techniques were employed to investigate nutrient profile trends.

Seasonal Variation Study

Composite tissue samples from 25 trees per plot with nine replications in three plantation ages were initially collected on August 20, 1983. These same trees, which were systematically located and flagged, were resampled on a monthly basis (20th of each month) through

August 20, 1984, excluding November, December, January, and February. Three separate sites, differentiated by topographic factors, were represented in the replications for each plantation. The 1977 plantation had sites quite similar with respect to landform (sideslopes) and slope (20-25 percent), yet aspects varied from northeast to southeast. The 1980 plantation had replications on various slopes (no slope, 5 and 20 percent) and aspects (no aspect, northeast, and southeast aspect). Replications within the 1982 plantation had the greatest topographic differences. Two sites on top of Bald Mountain (elevation 1340 m) were represented by a more mesic plateau with no slope or aspect and a sideslope facing east with a 17 % slope. The last site was located on an old cleared field at the base of the mountain (elevation 1080 m) with a southern aspect and 20 % slope.

Approximately 0.25 g of tissue from the current- and previous-year's needles (1982, 1983 growth) was combined from each tree within the replication. Sample locations were again restricted to 2- and 3-year-old primordial branches on the south side of the crown.

Data analysis focused on the variation for each nutrient as affected by time of year, plantation and foliage age. Monthly means for the 3 replications per plantation were tested for significant differences among plantation ages (2, 4, and 7 yrs) and foliage ages (1 yr and current) using ANOVA. Nutrient-level means for all replications combined were tested for differences between months using a one-way ANOVA. Where appropriate, multiple comparisons were applied to isolate differences in sampling periods, plantation ages, and foliage ages. Graphical techniques were employed to visually examine the nutrient variation through time to determine the nutrient level stability periods which may be suited for standardized sampling periods.

DRIS Study

In a 3-year-old plantation established in 1982, 79 trees were sampled to form the data base for the study. This plantation was selected since these trees were about one-half of the way through the rotation and appeared to represent an ideal growth stage to begin evaluating potential Christmas tree quality. Trees were selected on the basis of quality grade with approximately one third of the sample size chosen from each of the grades (U.S. Premium, U.S. # 1, and U.S. # 2).

Sample trees were chosen to represent the widest range in site variability. One third of the total samples, or about 25 trees, were taken at the base of the mountain where the third replication of the seasonal variation study is located. The remaining two-thirds of the sample trees were situated in the main 1982 plantation on top of the mountain, 310 m higher in elevation. A range in topographic diversity was represented for the samples collected from the top of the mountain. For this analysis a large amount of site variation was sought so that dissimilarities in nutrition and growth characteristics among trees would result.

Selection and tagging of study trees along with field measurement of tree variables was completed during the first two weeks of September, 1984. For each individual tree, the following data were collected:

1. basal diameter measured at groundline (cm).
2. current year's (1984) needle length measured from 2- and 3-year-old

primordial branches on the south side of the crown (mm).

3. number of apical buds on the current year's terminal leader.
4. length of the terminal bud on the terminal leader (mm).
5. current year's (3rd growing season) terminal leader length (cm).
6. number of whorled laterals which elongated from the node of the 2nd yr terminal leader.
7. number of whorled laterals which elongated from the node of the 1st yr terminal leader.
8. previous year's (2nd growing season) terminal leader length (cm).
9. number of laterals which elongated from the internode of the previous-year's terminal leader.
10. number of lateral buds in each successive 5 cm section on the current-year's terminal leader.
11. needle color on foliage from which needle length was determined (Munsell Color System).
12. Christmas tree grade (U.S Premium, U.S. # 1, U.S. # 2).

Also, current-year's foliage samples were collected on September 13, 1984, from each tree on the south side of the tree crown. Excised shoots for these samples were returned to the laboratory where needle length and color determinations were made prior to removing and drying the tissue.

Analysis of measured tree variables focused on comparison of means by grade and correlation of various attributes with tree-quality grade to investigate their relation to grade. For example, since crown fullness is influenced by bud frequency and subsequent elongation, the relationship between bud density and tree grade was analyzed. It should be noted that tree grades, as defined in this study, were subjective evaluations of the visual appeal of a Christmas tree. Hence, establishing a more objective description of quality via the measured tree variables seemed desirable in order to remove the subjectivity in tree performance evaluations. The main factors considered in tree grade were crown shape and fullness. Crown shape is primarily a function of the shearing regime the tree was subjected to, yet fullness is enhanced by the absence of holes in the crown and general branch and foliage density. Therefore, grade was considered a logical substitute for yield in the DRIS models, since it integrated all factors that affect Christmas tree quality. The development of an objective performance evaluation of tree quality was pursued with a discriminant analysis model to classify observations into the three grades.

Preliminary DRIS norms were developed according to standard procedures. The population of samples was divided into either desirable or undesirable subpopulations on the basis of tree grade. The nutrient elements determined for each tree were then expressed in many forms and compared between the two populations. For example, with nitrogen, forms included N concentration of dry matter, N/P, N/K, etc. Means, standard deviations, variances, and coefficients of variation for the different forms were computed for each subpopulation. Tests for differences in means and variances were performed for these groups. The forms of expression which had significant variance ratios (S^2bad/S^2good) between the two populations were considered discriminatory and kept for the development of DRIS index equations.

Foliar Chemical Analysis

Foliar chemical analyses for each tissue sample included determinations of N, P, K, Ca, and Mg concentrations by standard techniques used in the Forestry Department's Tree Nutrition Laboratory. All tissue samples were handled and stored according to standard procedures. Needle tissue which was stripped in the field and placed in paper bags was dried immediately upon return to the lab. Branches collected in the field were kept in plastic bags under refrigeration until the needles could be stripped in the laboratory. This method proved effective in minimizing moisture losses from the needles, which was important in maintaining foliage color. Tissue samples were dried at 65^{o}C (48 hr) and ground in a Wiley mill to pass a 1 mm sieve. Ground samples were stored in coin envelopes under refrigeration (4^{o}C) until needed for laboratory analysis. Prior to weighing individual samples, the tissue was redried at 65^{o}C for at least 24 hr.

Nitrogen determinations were performed by the Total Kjeldahl Nitrogen (TKN) distillation and ammonia-salicylate colorimetric technique on a Technicon Autoanalyzer. Means for replicates from each method were used for the first two studies only. The DRIS study only utilized the Autoanalyzer method. Phosphorus determinations were performed by the dry-ashing ascorbic acid technique and a wet digestion Murphy Riley chemistry on the Autoanalyzer. The other three cations were determined by atomic absorption spectrophotometry on dry ash extractions.

PAPER NUMBER 1

Temporal and Spatial Variability of Foliar Nutrient Levels in Fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas Trees

Keywords:

Tissue analysis, seasonal variation, within-tree variation, tree to tree variation, sampling intensity

(ABSTRACT)

Three studies were conducted with Fraser fir Christmas trees to determine the variation in foliar nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) levels among plantation ages, sample locations within the crown, and effects due to seasonal changes. Extensive variation in nutrient concentrations existed with age of tissue collected, sample location with respect to aspect and vertical position, and normal seasonal fluctuation. Tree to tree nutrient variation indicated that greater sampling intensities are required for younger (under 4 yr) plantations as opposed to older (over 4 yr) plantations to achieve comparable confidence and precision levels. The data clearly illustrated that comparisons of foliar nutrient levels without regard to these sampling variables could cause erroneous diagnoses. Recommended foliar sampling practices involve sampling current-year's tissue from 2- or 3-year-old south-facing branches in October or November for routine foliar diagnoses.

INTRODUCTION

The very important role of fertilizers for increasing crop production has led to the development of specialized soil extraction and analysis techniques. Soil analyses are extremely valuable and are used on a large scale in agriculture for forecasting fertilizer needs, yet they 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.

Foliar 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 fertilizers. 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; Wells and Metz, 1963; Miller, 1966; Lowry and Avard, 1969; Everard, 1973; Mead and Pritchett, 1974).

To keep field and sampling variation to a minimum, standard sampling procedures have been adopted by most researchers. For conifers, current- season's foliage of the top whorls is usually sampled during autumn or winter (White, 1954; Wells and Metz, 1963; Lowry and Avard, 1969; Everard, 1973). However, some scientists have questioned whether this sampling scheme is the most sensitive for detecting site- or fertilizer-treatment differences (Leaf, 1973; Mead and Pritchett, 1974).

Recently, there has been considerable interest in the mineral nutrition of Fraser fir Christmas trees with respect to diagnosing deficiencies and response to fertilizer. For this species, nutritional assessments and response predictions using foliar analysis have been met with very limited success. Part of the problem is a limited knowledge of the factors that control plant nutrient levels, and the imprecision of diagnostic tools applied to tissue collected under different sampling conditions.

Accurate evaluations of plantation nutrient requirements should initially involve a characterization of the variables mentioned followed by the establishment of standard foliar sampling techniques. Reduced to its simplest form, the Fraser fir Christmas tree manager might hope that the routine sampling and testing of a few selected trees for one or more nutrients will show whether fertilization is required, and, if so, what quantities of what types of fertilizer are needed.

The purpose of this study was to characterize Fraser fir foliar nutrient variation as affected by plantation age, distribution within the tree crown, and seasonal change for two foliage ages in order to formulate standard foliar sampling procedures for Fraser fir Christmas trees.

METHODS

Study Area

The study area is located on Bald Mountain (lat. 36°21'N, long. 81°39'W) in Watauga county, North Carolina where plantation-grown Fraser fir Christmas trees are intensively managed on high elevation (>1310 m) grassy balds. Fraser fir Christmas tree production on these sites requires 7 to 9-yr rotations after establishing plantations with 5-year-old seedlings. Cultural treatments include regular fertilization, shearing, mowing, and chemical vegetation and pest control.

The site, situated in the heart of the Blue Ridge physiographic province, has a climate that is moderated by the mountainous terrain. Adequate moisture (130 cm of mean annual total precipitation) is generally available during the relatively short growing season (approximately 140 frost free days) that exists on these mountain-tops (Nelson and Zillgitt, 1969). Average normal daily January and June temperatures are 1 and 20°C, respectively. Soils of the study area predominantly represent the Ashe (coarse-loamy, mixed, mesic, Typic Dystrochrept) and Watauga series (fine-loamy, mixed, mesic, Typic Hapludult), which are medium to moderately heavy-textured soils with many coarse fragments weathered from residuum or colluvium of high grade metamorphic composites.

Field Sampling and Chemical Analysis

Fall-collected tissue samples from 20 trees in each of 3 plantation ages (2, 4, and 7 years) were analyzed to determine within-plantation variation. Current- and previous-year's needles on 2- and 3-year-old south-facing branches were removed from each tree. Trees were randomly selected within topographically uniform areas of about 0.4 ha.

Within-tree nutrient variation was investigated on 10 randomly selected trees within a 7-year-old plantation. Needles from 24 sample locations differentiated by cardinal direction (north and south), whorl age (1, 2, 3, 4, and 5 years), and foliage age (1, 2, and 3 years) were excised in late fall from each tree. Thus, for each crown aspect, 12 tissue samples for each of the top 5 crown heights and 3 most recent foliage ages were obtained for analysis.

Composite tissue samples from 25 trees per plot with 3 plot replications in each of the 3 plantation ages were collected monthly for one year to form the basis of a seasonal variation study. Current- and previous-season's needles were sampled from each plot on the 20th of each month from August, 1983 until August, 1984, with the exception of November, December, January, and February when access to the mountain was limited by snow and ice. The plot locations were selected to represent the extremes in topography present in each plantation. Sampling locations were again restricted to 2- and 3-year-old whorls on the south side of the crown.

Tissue handling, storage, preparation, and chemical analysis techniques were similar for the three studies. All foliage samples were oven-dried (65°C) and ground to pass a 1 mm sieve. Sample N and P concentrations in Kjeldahl acid digests were colorimetrically analyzed on a Technicon Autoanalyzer via the ammonia-salicylate and phosphomolybdate complex, respectively. Spectrophotometric determinations of K, Ca, and Mg were performed on ashed (500^{o}C for 24 hr) subsamples extracted in 6M hydrochloric acid. Calcium and Mg were analyzed via atomic absorption using lanthanum to suppress interferences. Potassium was determined via atomic emission using sodium to overcome ionization interferences.

RESULTS

Within-Plantation Variation Study

Numerous nutrient level differences between plantation ages (Table 1) and foliage ages (Table 2) were observed. Unequal-variance tests indicated differing variability for most of the same nutrients exhibiting different mean levels (Table 2). Hence, it was hypothesized that the F-tests were influenced by the location of the mean. To test this hypothesis sample observations were adjusted (multiplied) by a constant value so that sample means were identical. F-tests on these adjusted samples or adjusted variances reflected differences in the coefficients of variation (CV) since they were not affected by the adjustment. Contrasting coefficients of variation has intuitive meaning since they are related to sample size estimates (Tables 3 and 4).

Nutrient variability differences between current- and previous-season's foliage for all 3 plantation ages combined showed that the more mobile elements (N, P, and K) were more variable in current-year's tissue, yet the reverse was apparent for the less mobile Mg and immobile Ca (Table 2). Although variances for N, P, and K appeared significantly larger in current-season's needles, the adjusted F-test indicated variability tests were influenced by the lower nutrient means in the older tissue. Potassium was the only element with a larger coefficient of variation in younger foliage (19.1 versus 14.4). The greater Ca variability observed in older tissue (21.6) was also nonsignificant on a relative variation basis. A larger range in nutrient variation existed for the older foliage (CV's of 10.6 to 39.3) as compared to younger

Table 1. Comparison of current-year's foliar nutrient means and variances between different Fraser fir Christmas tree plantation ages in Watauga county, N.C. Statistics for each plantation age are based on a sample of 20 trees.

Nutrient	Two-year-old trees			Four-year-old trees			Seven-year-old trees		
	Mean (%)	Variance	C.V.	Mean (%)	Variance	C.V.	Mean (%)	Variance	C.V.
N	1.956b[1]	0.074a[2]	13.9a[3]	2.166a	0.053a	10.6a	1.861b	0.030a	9.3a
P	0.252a	0.0018a	16.7a	0.269a	0.0011a	12.6ab	0.210b	0.0004b	9.1b
K	0.614b	0.013a	18.4a	0.787a	0.020a	17.9a	0.713a	0.008a	12.8a
Ca	0.477a	0.009a	19.9a	0.455a	0.002b	8.8b	0.373b	0.005a	18.0a
Mg	0.136a	0.0014a	27.3a	0.076c	0.0002b	20.5a	0.115b	0.0004b	17.7a

[1] Means for each nutrient (rows) identified by similar letters are not significantly different via Fishers' T-test ($P \le 0.05$).

[2] Variances for each nutrient (rows) identified by similar letters are not significantly different via an F-test ($P \le 0.05$).

[3] Coefficients of variation for each nutrient (rows) identified by similar letters are not significantly different via an F-test on adjusted variances ($P \le 0.05$).

Table 2. Comparison of nutrient means and variances between two foliage ages for 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga Co., N.C. Statistics are based on 60 samples pooled across plantation age.

Nutrient	Current season's needles			Previous season's needles		
	Mean	Variance	C.V.	Mean	Variance	C.V.
	(%)			(%)		
N	1.993a[1]	0.067a[2]	13.0a[3]	1.533b	0.026b	10.6a
P	0.243a	0.0017a	16.9a	0.163b	0.0007b	16.4a
K	0.702a	0.018a	19.1a	0.504b	0.005b	14.4b
Ca	0.435b	0.007b	19.4a	0.548a	0.014a	21.6a
Mg	0.110a	0.0013a	32.3a	0.102a	0.0016a	39.3a

[1] Means for each nutrient (rows) identified by similar letters are not significantly different via Fishers' T-test ($P \leq 0.05$).

[2] Variances for each nutrient (rows) identified by similar letters are not significantly different via an F-test ($P \leq 0.05$).

[3] Coefficients of variation for each nutrient (rows) identified by similar letters are not significantly different via an F-test on adjusted variances ($P \leq 0.05$).

Table 3. Comparison of sample size requirements with current-year's foliage for different Fraser fir Christmas tree plantation ages in Watauga county, N.C. Sampling intensity requirements based on mean and variance estimates from a pilot sample of 20 trees.

Nutrient	Two-year-old trees				Four-year-old trees				Seven-year-old trees			
	Mean	Sample size			Mean	Sample size			Mean	Sample size		
		Error tolerance				Error tolerance				Error tolerance		
	(%)	.2x	.1x	.05x	(%)	.2x	.1x	.05x	(%)	.2x	.1x	.05x
N	1.956	2[1]	9	34	2.166	2	5	20	1.861	1	4	16
P	0.252	3	12	49	0.267	2	7	28	0.210	1	4	15
K	0.614	4	15	59	0.787	4	14	57	0.713	2	7	29
Ca	0.477	5	17	69	0.455	1	4	14	0.373	4	14	57
Mg	0.136	8	33	130	0.076	5	19	74	0.115	4	14	55

[1] 95% confidence sample size estimates $N = [(t_{.975})^2 \times s^2]/(\text{error tolerance})^2$

Table 4. Comparison of sample size requirements for two foliage ages and five nutrients with 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga County, N.C. Sampling intensity requirements based on means and variances from a sample of 60 trees pooled across plantation ages.

Nutrient	Current season's needles				Previous season's needles			
	Mean	Sample size			Mean	Sample size		
		Error tolerance				Error tolerance		
	(%)	.2x	.1x	.05x	(%)	.2x	.1x	.05x
N	1.993	2[1]	7	26	1.533	1	5	17
P	0.243	3	11	44	0.163	3	10	41
K	0.702	4	14	56	0.504	2	8	32
Ca	0.435	4	15	58	0.548	5	18	72
Mg	0.110	10	40	160	0.102	15	60	238

[1] 95% confidence sample size estimate = $[(t_{.975})^2 \times s^2]/(\text{error tolerance})^2$

foliage (CV's of 13.0 to 32.3).

Tree to tree nutrient variability in young foliage increased in the order N, P, K, Ca, and Mg as indicated by larger coefficients of variation (Table 2) and concomitant sample size estimates (Table 4). The order of nutrient variability in older tissue was similar with P exhibiting slightly higher variation than K.

Foliar nutrient variability tended to decrease with increasing plantation age for all nutrient elements, except Ca where the intermediate aged (4 years) plantation showed the least variation (Table 1). Sampling intensities needed to detect N (least variable element) concentration differences within 10% of the mean in 2- and 7-year-old plantation are 9 and 4, respectively (Table 3). Similar standard confidence (95%) estimates of required sample sizes for the most variable element (Mg) in the same plantation ages are 33 and 14, respectively. Differences in these two sets of estimates reflect a considerable variability effect due to the age of the plantation sampled and the particular nutrient element of interest.

Within-Tree Variation

Generally higher levels of the 5 nutrients were observed on the southern as opposed to the northern crown exposure, yet the magnitude of this increase varied slightly among nutrients (Tables 5 to 9). All sample locations considered, N, P, K, Ca, and Mg concentrations averaged 4, 5, 9, 6, and 6 % higher on the southern aspect, respectively. Trends in current-season's tissue were quite consistent since all elements were four % higher on south versus north cardinal positions. The elevated N,

Table 5. Mean nitrogen concentration by aspect, whorl and foliage age for Fraser fir Christmas trees within a 7-year-old plantation in Watauga County, North Carolina.

Whorl age	North aspect Foliage age 1	North aspect Foliage age 2	North aspect Foliage age 3	South aspect Foliage age 1	South aspect Foliage age 2	South aspect Foliage age 3
	(%)					
1	2.08(a)[1]	-	-	2.16(a)	-	-
2	2.08(a,1)	1.67(a,2)	-	2.16(a,1)	1.69(a,2)	-
3	2.10(a,1)	1.63(a,2)	1.40(a,3)	2.14(a,1)	1.73(a,2)	1.44(a,3)
4	2.05(a,1)	1.68(a,2)	1.43(a,3)	2.16(a,1)	1.78(a,2)	1.43(a,3)
5	2.07(a,1)	1.68(a,2)	1.45(a,3)	2.19(a,1)	1.80(a,2)	1.49(a,3)
Mean	2.08(1)	1.66(2)	1.43(3)	2.16(1)*[2]	1.75(2)*	1.45(3)

[1] Common letters or numbers within a column or row, respectively, indicate no difference ($P \leq 0.05$).

[2] Means marked with an * indicate higher levels ($P \leq 0.05$) than corresponding foliage age means on the north aspect.

Table 6. Mean phosphorus concentration by aspect, whorl and foliage age for Fraser fir Christmas trees within a 7-year-old plantation in Watauga County, North Carolina.

Whorl age	North aspect Foliage age 1	North aspect Foliage age 2	North aspect Foliage age 3	South aspect Foliage age 1	South aspect Foliage age 2	South aspect Foliage age 3
	(%)					
1	0.221(a)[1]	-	-	0.226(a)	-	-
2	0.227(a,1)	0.144(a,2)	-	0.231(a,1)	0.146(a,2)	-
3	0.226(a,1)	0.137(a,2)	0.112(a,3)	0.228(a,1)	0.150(a,2)	0.116(a,3)
4	0.216(a,1)	0.144(a,2)	0.114(a,3)	0.223(a,1)	0.157(a,2)	0.119(a,3)
5	0.204(a,1)	0.144(a,2)	0.117(a,3)	0.226(a,1)	0.159(a,2)	0.122(a,3)
Mean	0.219(1)	0.142(2)	0.114(3)	0.227(1)	0.153(2)*[2]	0.119(3)

[1] Common letters or numbers within a column or row, respectively, indicate no difference ($P \leq 0.05$).

[2] Means marked with an * indicate higher levels ($P \leq 0.05$) than corresponding foliage age means on the northern aspect.

Table 7. Mean potassium concentration by aspect, whorl and foliage age for Fraser fir Christmas trees within a 7-year-old plantation in Watauga County, North Carolina.

Whorl age	North aspect Foliage age 1	North aspect Foliage age 2	North aspect Foliage age 3	South aspect Foliage age 1	South aspect Foliage age 2	South aspect Foliage age 3
	(%)					
1	0.921(a)[1]	-	-	0.948(a)	-	-
2	0.814(ab,1)	0.586(a,2)	-	0.808(ab,1)	0.649(a,2)	-
3	0.817(ab,1)	0.550(a,2)	0.462(a,2)	0.776(b,1)	0.619(a,2)	0.508(a,3)
4	0.684(bc,1)	0.577(a,12)	0.485(a,3)	0.744(b,1)	0.611(a,2)	0.505(a,3)
5	0.647(c,1)	0.554(a,2)	0.397(a,3)	0.760(b,1)	0.624(a,2)	0.478(a,3)
Mean	0.776(1)	0.567(2)	0.447(3)	0.807(1)	0.626(2)*[2]	0.497(3)*

[1] Common letters or numbers within a column or row, respectively, indicate no difference ($P \leq 0.05$).

[2] Means marked with an * indicate higher levels ($P \leq 0.05$) than corresponding foliage age means on the north aspect.

Table 8. Mean calcium concentration by aspect, whorl and foliage age for Fraser fir Christmas trees within a 7-year-old plantation in Watauga County, North Carolina.

Whorl age	North aspect Foliage age			South aspect Foliage age		
	1	2	3	1	2	3
	(%)					
1	0.423(a)[1]	-	-	0.447(a)	-	-
2	0.323(c,2)	0.513(a,1)	-	0.374(a,1)	0.505(ab,1)	-
3	0.360(bc,2)	0.428(a,12)	0.502(a,1)	0.368(a,2)	0.448(b,12)	0.533(a,1)
4	0.405(ab,1)	0.419(a,1)	0.431(a,1)	0.415(a,1)	0.470(b,1)	0.465(a,1)
5	0.445(a,1)	0.512(a,1)	0.499(a,1)	0.436(a,2)	0.584(a,1)	0.531(a,12)
Mean	0.391(2)	0.468(1)	0.479(1)	0.408(2)	0.502(1)	0.509(1)

[1] Common letters or numbers within a column or row, respectively, indicate no difference ($P \leq 0.05$).

Table 9. Mean magnesium concentration by aspect, whorl and foliage age for Fraser fir Christmas trees within a 7-year-old plantation in Watauga County, North Carolina.

Whorl age	North aspect, Foliage age 1	North aspect, Foliage age 2	North aspect, Foliage age 3	South aspect, Foliage age 1	South aspect, Foliage age 2	South aspect, Foliage age 3
	(%)					
1	0.150(a)[1]	-	-	0.160(a)	-	-
2	0.120(b,1)	0.130(a,1)	-	0.118(b,1)	0.134(a,1)	-
3	0.125(b,1)	0.096(b,2)	0.098(a,2)	0.130(b,1)	0.103(ab,2)	0.107(a,12)
4	0.137(ab,1)	0.099(ab,2)	0.093(a,2)	0.139(ab,1)	0.101(b,2)	0.096(a,2)
5	0.136(ab,1)	0.111(ab,2)	0.098(a,2)	0.143(ab,1)	0.125(ab,12)	0.104(a,2)
Mean	0.133(1)	0.109(2)	0.096(3)	0.138(1)	0.116(2)	0.104(2)

[1] Common letters or numbers within a column or row, respectively, indicate no difference ($P \leq 0.05$).

P, and K levels on the southern exposure were significant for some tissue ages (Tables 5 to 7).

Comparison of elemental concentration changes between foliage ages revealed significant differences between current and previous season's tissue for all nutrients, regardless of aspect (Tables 5 to 9). Considerable retranslocation of N, P, and K occurred on most whorls since concentrations were different among all three foliage ages. The lesser mobility of Mg is apparent with fewer increases with foliage age; whereas, the immobility of Ca is demonstrated by the consistently lower concentrations in younger tissue.

Vertical nutrient distribution trends are graphically illustrated in Figures 1 to 5. Vertical nutrient distributions within the tree crown exhibited by N and P were constant, regardless of tissue age. Marked decreases in potassium content with older whorl ages were observed in the youngest tissue only. Similar gradients for Ca and Mg demonstrated depressed levels at intermediate whorl ages, especially with the two youngest needle ages.

Tree to tree nutrient variability in current- and previous-season's tissue tended to be slightly lower in southern versus northern exposure for N, P, and K when all whorl ages where considered, whereas a reverse tendency was detectable for Ca and Mg (Table 10). Similarly, lower variation across all whorl ages in current- versus previous-year's foliage was observed for N, Ca, and Mg, while the opposite trend was exhibited with P and K. Consistent vertical variability trends were not apparent for any element. All foliage ages considered, the nutrient variability ordering (N, P, Ca, Mg, K) parallels that found in the

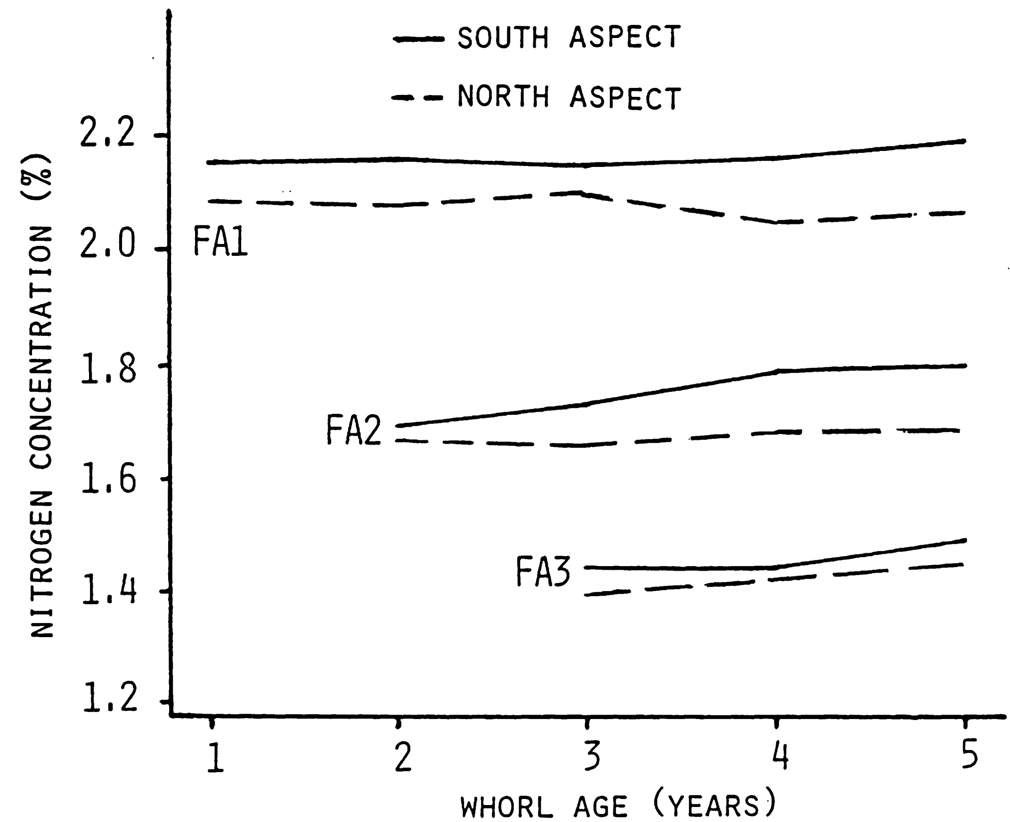

Figure 1. Nitrogen concentration profile in trees within a 7-year-old Fraser fir Christmas tree plantation. FA indicates foliage age.

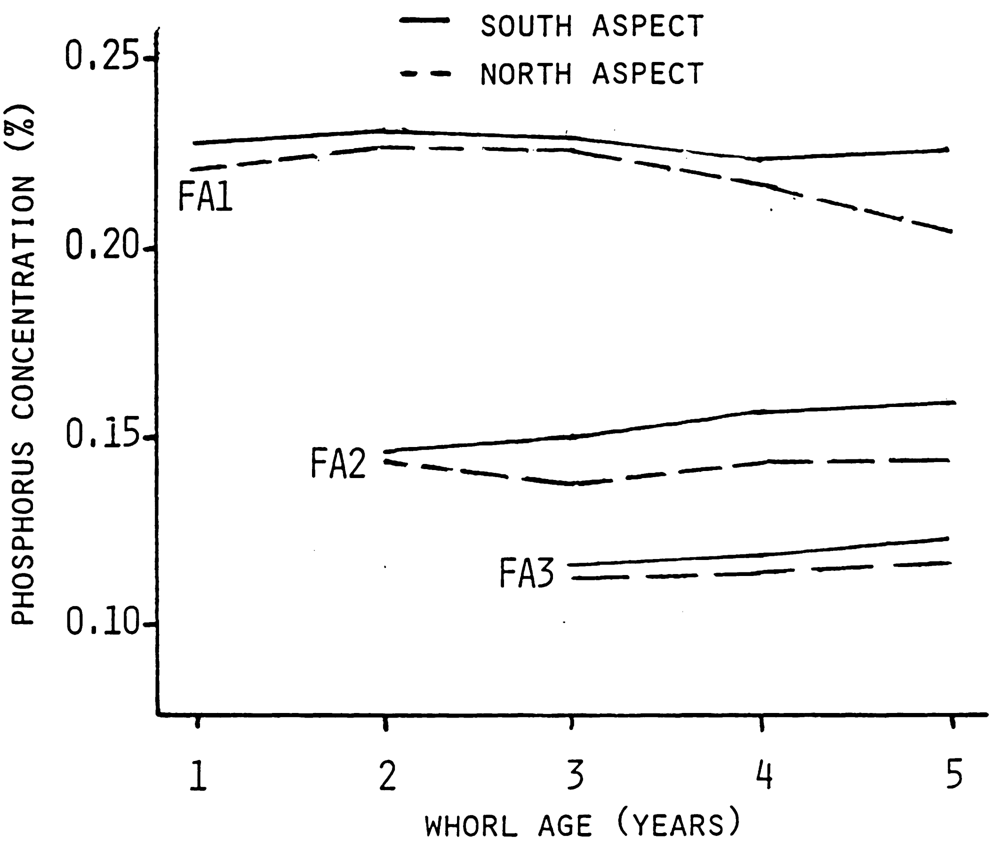

Figure 2. Phosphorus concentration profile in trees within a 7-year-old Fraser fir Christmas tree plantation. FA indicates foliage age.

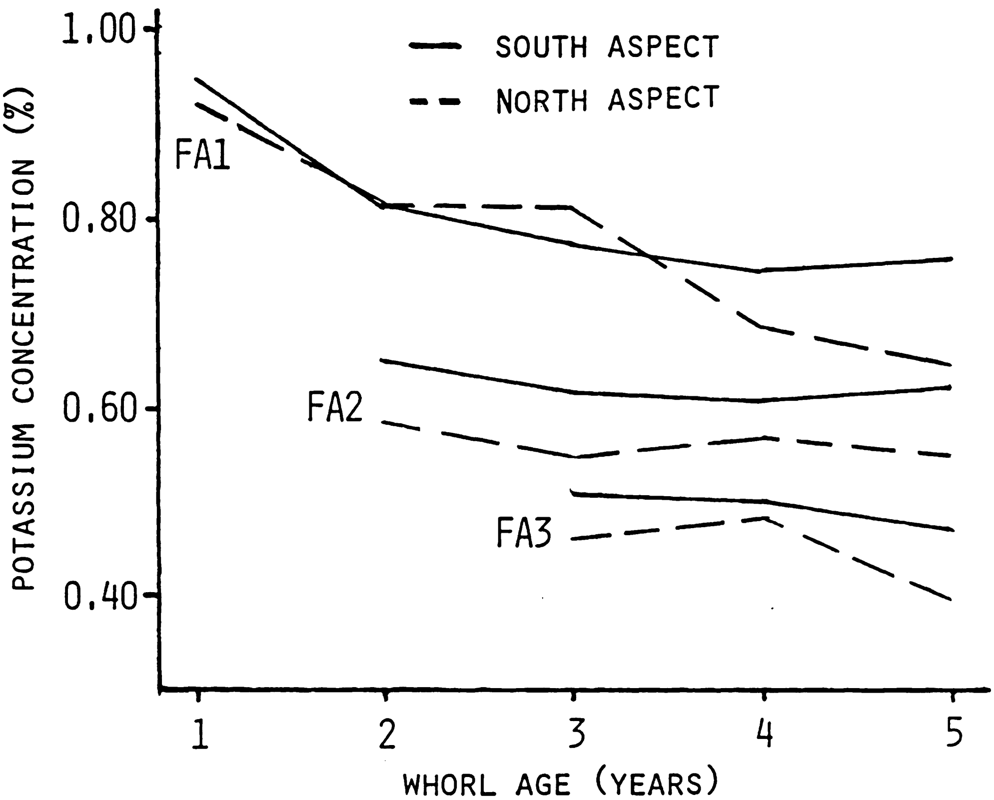

Figure 3. Potassium concentration profile in trees within a 7-year-old Fraser fir Christmas tree plantation. FA indicates foliage age.

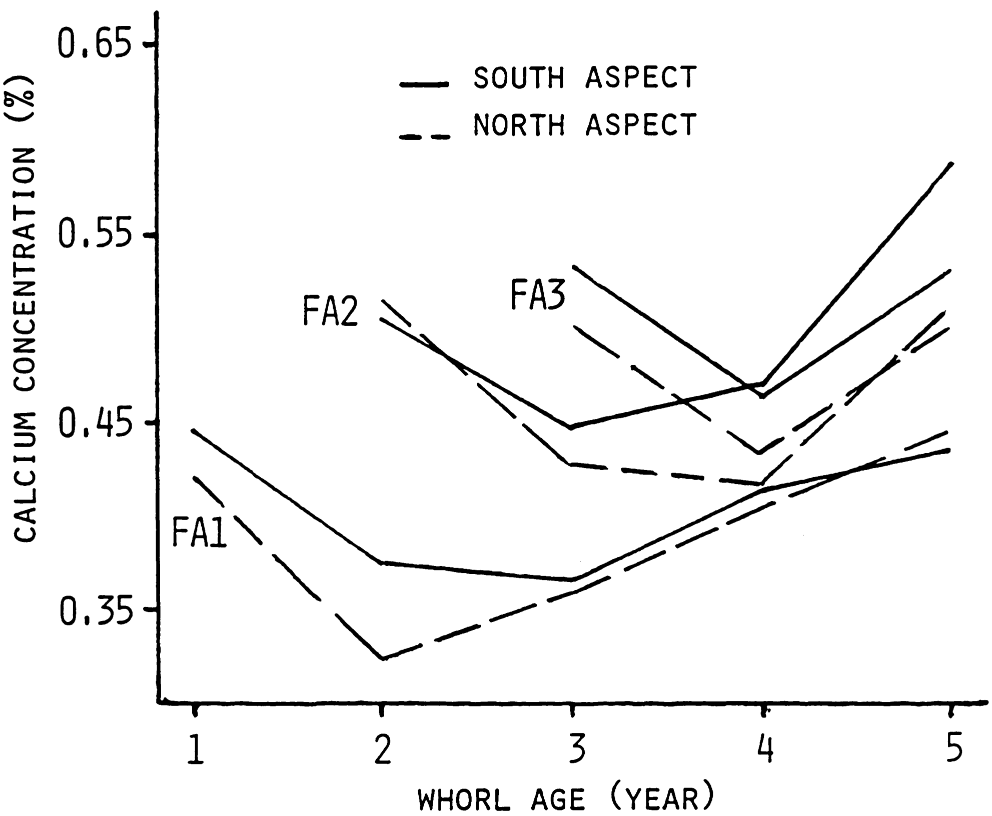

Figure 4. Calcium concentration profile in trees within a 7-year-old Fraser fir Christmas tree plantation. FA indicates foliage age.

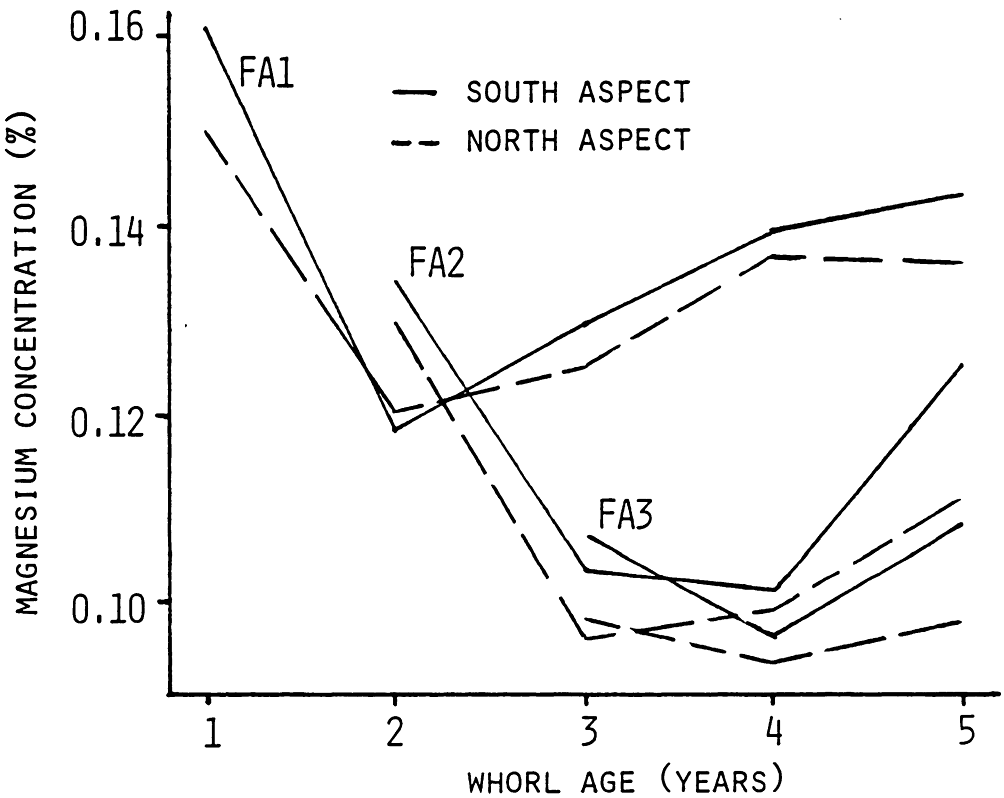

Figure 5. Magnesium concentration profile in trees within a 7-year-old Fraser fir Christmas tree plantation. FA indicates foliage age.

Table 10. Coefficients of variation (%) for each nutrient by aspect, whorl and foliage age in Fraser fir Christmas trees within a 7-year-old plantation in Watauga county, North Carolina.

Whorl age	North aspect Foliage age			South aspect Foliage age		
	1	2	3	1	2	3
			Nitrogen			
1	8.3	-	-	6.8	-	-
2	9.9	9.1	-	6.3	9.3	-
3	7.8	11.7	12.5	8.6	8.3	17.2
4	11.4	8.1	12.1	6.7	9.3	12.2
5	9.9	9.9	8.9	8.6	11.1	12.2
			Phosphorus			
1	15.0	-	-	11.5	-	-
2	14.3	10.4	-	11.6	6.8	-
3	9.4	13.9	11.5	14.2	9.0	14.3
4	13.9	9.1	12.2	10.3	7.6	13.2
5	13.2	10.0	10.5	6.5	10.9	17.4
			Potassium			
1	20.9	-	-	22.3	-	-
2	22.2	23.0	-	23.6	18.8	-
3	13.4	23.1	24.5	21.4	12.3	17.1
4	26.5	12.8	12.8	14.7	18.2	13.6
5	14.3	15.8	20.2	15.7	10.6	20.9
			Calcium			
1	18.6	-	-	22.3	-	-
2	17.7	32.2	-	16.0	38.4	-
3	16.3	19.5	23.1	13.7	13.9	26.3
4	14.1	14.4	12.1	13.1	15.6	13.4
5	15.9	18.0	15.8	30.4	16.4	15.7
			Magnesium			
1	20.7	-	-	22.8	-	-
2	19.3	40.3	-	18.2	42.7	-
3	14.6	22.0	27.8	22.5	14.5	32.3
4	14.2	19.3	15.2	18.3	24.7	15.7
5	19.7	24.0	18.3	13.5	14.5	23.4

within-plantation variation study, although greater variation for K in the youngest tissue was observed with these results.

Seasonal Variation Study

A major study objective was to identify possible sampling dates that may be best suited for standard foliar sampling practices. Nutrient concentrations averaged across all sampling dates were different among some plantation ages, regardless of foliage age (Table 11). These results were expected, since site and fertilizer source and rate application differences existed in addition to the dissimilar plantation ages. Plots of current-year's foliage concentration by sampling date shows the period during the season that is best for sampling (Figures 6 and 7). Note that dashed lines connect October to March sampling dates since tissue collections during the winter months were not available. In the absence of these data valuable information on the exact nature of winter separations was lost. However, from experience it was known that this species on these high elevation sites entered true dormancy during this period. Hence, minimal physiological activity and concomitant deviation from these lines was expected.

Sampling dates that most clearly delineated the plantation differences varied according to the nutrient element considered. Nitrogen and P differences seemed to be best defined by autumn (September and October) collections, whereas, K and Ca divergences were more noticeable during the summer (June and July). Seasonal Mg differences were not discernable; there were conflicting patterns from month to month (data for Mg are not shown).

Table 11. Mean nutrient levels by plantation age averaged across all sampling dates for Fraser fir Christmas trees in Watauga county, N.C. Means separation based on Duncan's new multiple range test using sampling date as a covariate.

Plantation age	Foliage age: Current-year's	Foliage age: Previous-year's
	(%)	
	Nitrogen	
2	1.95 a[1]	1.50 b
4	1.92 a	1.57 a
7	1.75 b	1.55 ab
	Phosphorus	
2	0.165 a	0.130 a
4	0.176 a	0.123 a
7	0.138 b	0.110 b
	Potassium	
2	0.506 b	0.369 c
4	0.562 a	0.420 b
7	0.580 a	0.464 a
	Calcium	
2	0.455 a	0.498 a
4	0.433 a	0.517 a
7	0.385 b	0.538 a
	Magnesium	
2	0.106 a	0.098 a
4	0.090 b	0.070 b
7	0.085 b	0.081 b

[1] Common letters within a foliage age indicate no significant difference ($P \leq 0.05$).

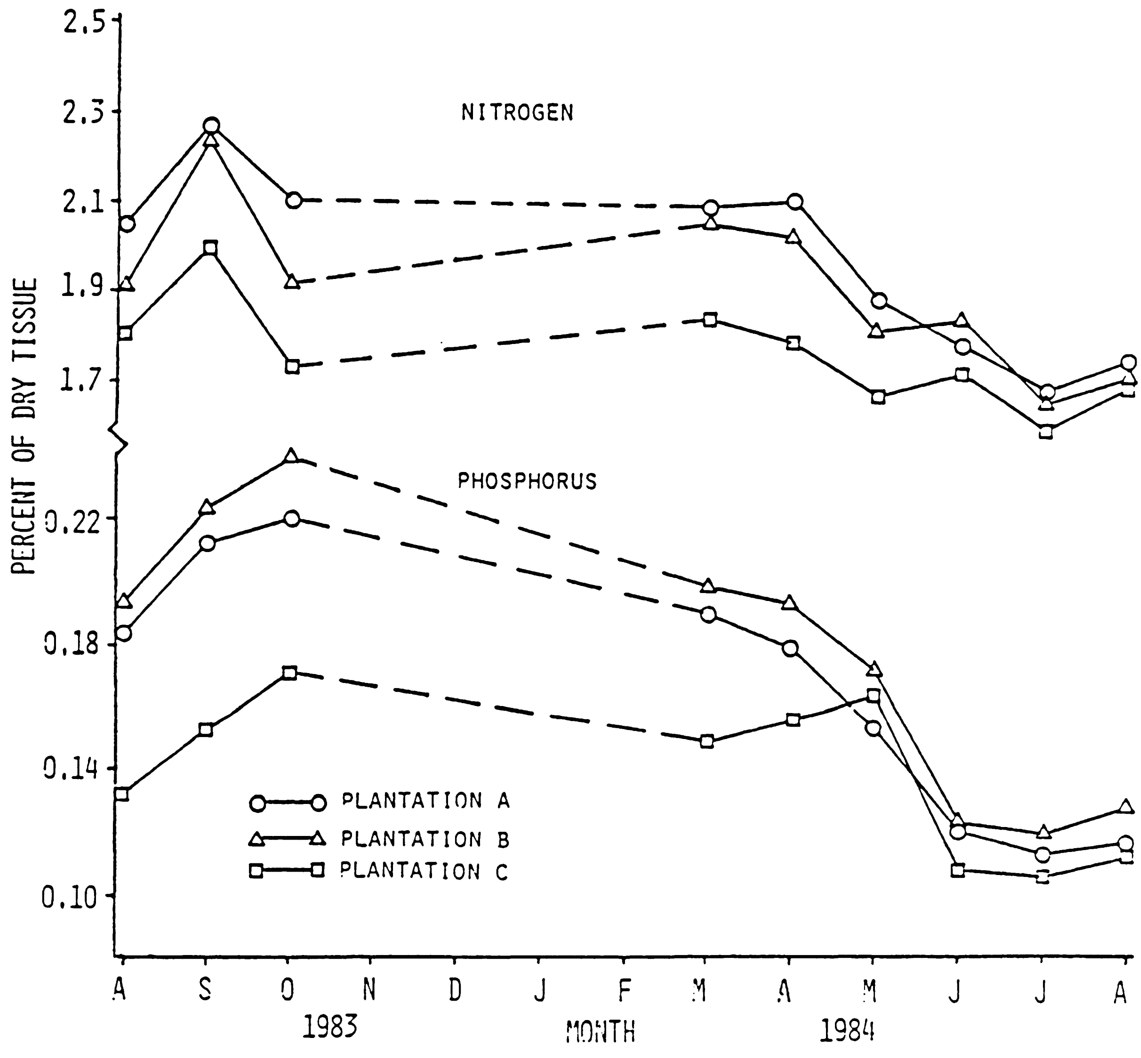

Figure 6. Seasonal N and P fluctuations in current-year's foliage for three Fraser fir Christmas tree plantations on different sites and of different ages in Watauga county, North Carolina.

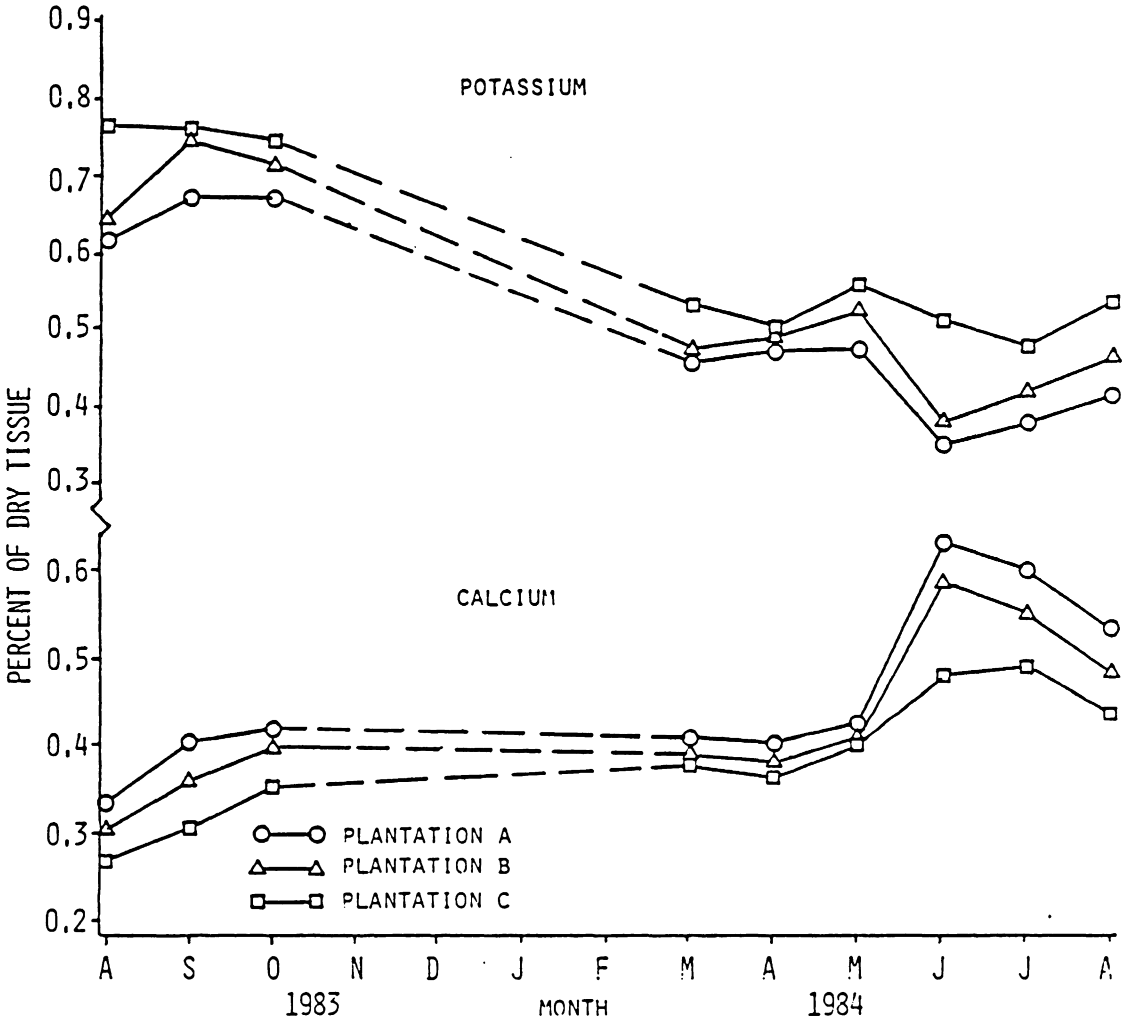

Figure 7. Seasonal K and Ca fluctuation in current-year's foliage for three Fraser fir Christmas tree plantations on different sites and of different ages in Watauga county, North Carolina.

Similar seasonal patterns for N, P, K, and Ca among plantations indicated that a stable seasonal sampling window could be selected based on plantation averages. Combined data are presented in Figures 8 to 12. Current-year's foliage refers to needle growth that occurred during the growing season (1983) when sampling was initiated. Consequently, the last four months of sampling (1984 growing season), current-year's foliage was actually previous-year's tissue.

Extensive seasonal fluctuation in foliar N, P, K, and Ca levels was evident, especially within the current-year's foliage (Figures 8 to 11). Seasonal responses in previous-year's tissue, for the three mobile elements (N, P, and K), tended to mimic current-year's foliage patterns at a dampened level. This probably reflects the diminished physiological activity occurring in older tissue. In contrast, Mg fluctuation in both tissue ages apparently occurs at a decreased level. Differences in monthly nutrient concentrations were investigated for each foliage age-nutrient element combination via Duncan's new multiple range test and are indicated by dissimilar letters (Figures 8 to 12). Due to the dependence of successive tissue collections from the same sets of trees, the error rates specified are not exact but approximate levels. Significant differences between sampling dates for both tissue ages existed for all elements, except Mg, especially during the active growing season.

Considerable nutrient mobility (N, P, and K) or immobility (Ca) is evidenced by significantly higher or lower concentrations in current-versus previous-year's tissue, respectively (Figures 8 to 10). Sampling months where the two foliage ages differed are identified by asterisks

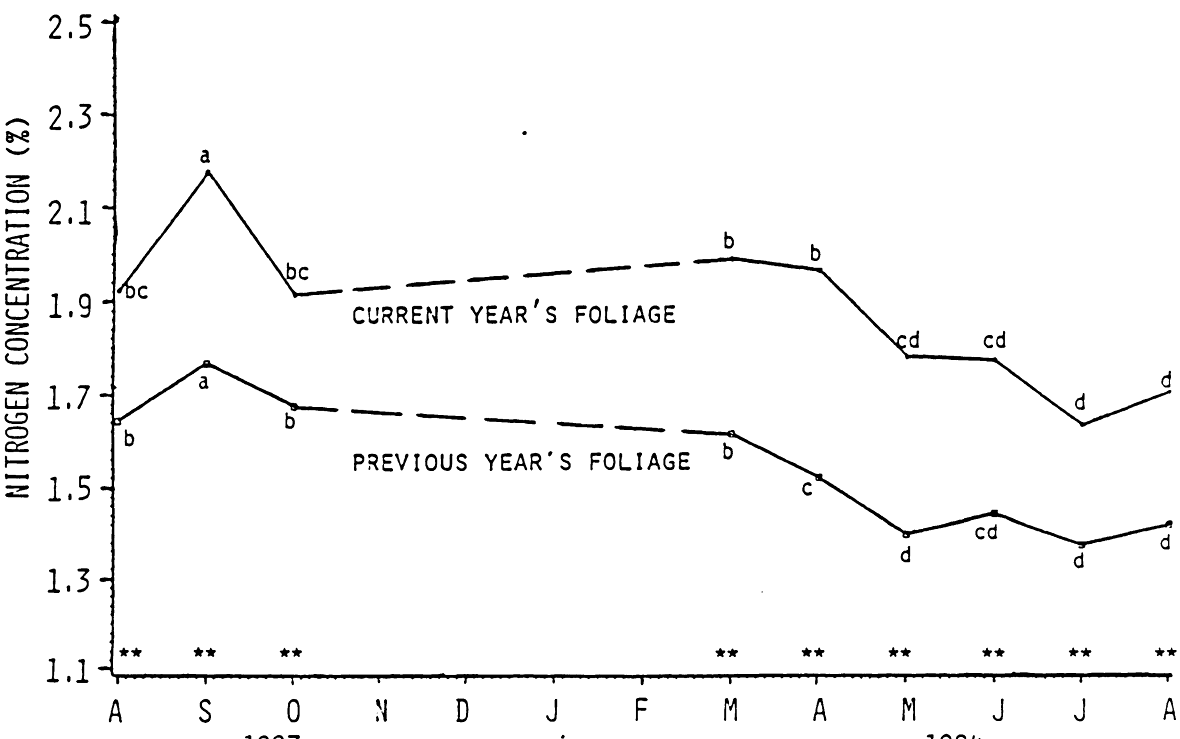

Figure 8. Seasonal N fluctuation in current and previous-year's foliage on 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga county, N.C. Months within a foliage age with dissimilar letters are significantly different ($P \leq 0.05$). Months labeled with * and ** indicate different foliage ages ($P \leq 0.05$, and $P \leq 0.01$, respectively).

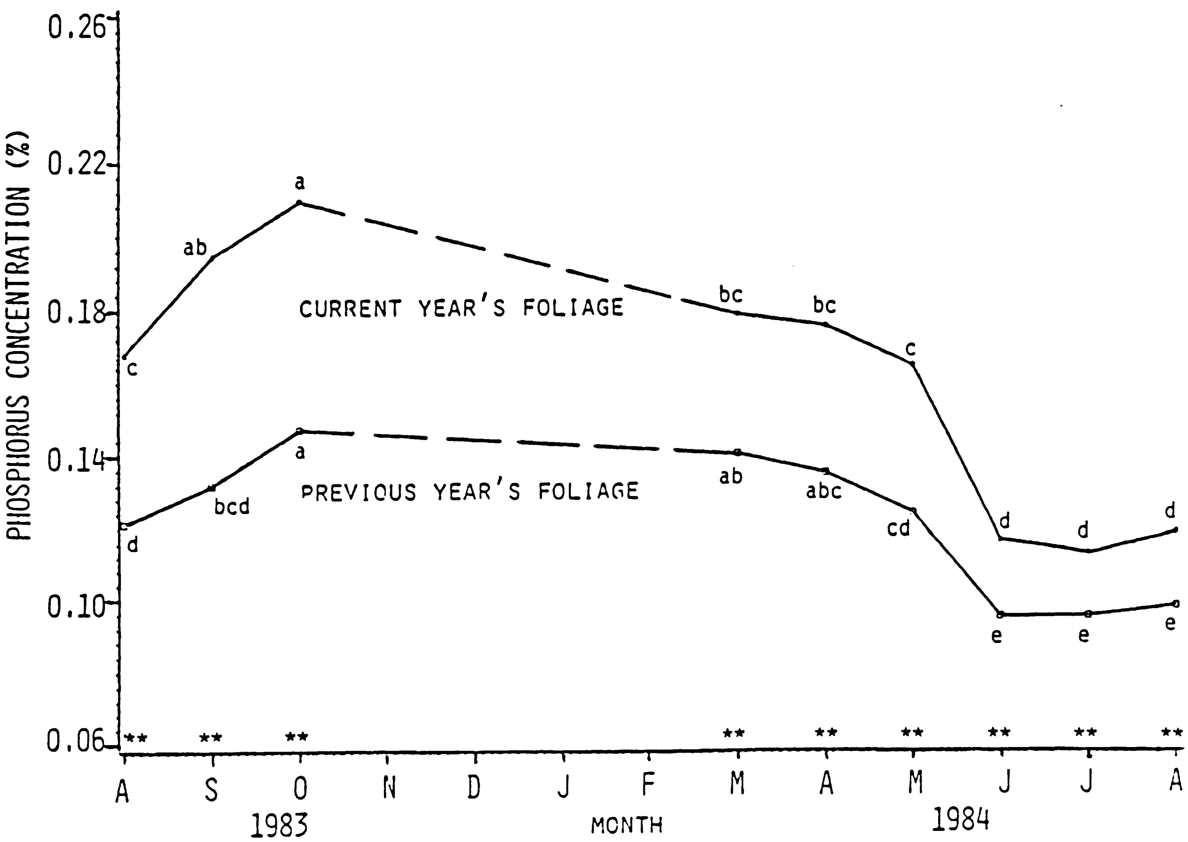

Figure 9. Seasonal P fluctuation in current and previous-year's foliage on 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga county, N.C. Months within a foliage age with dissimilar letters are significantly different ($P \leq 0.05$). Months labeled with * and ** indicate different foliage ages ($P \leq 0.05$, and $P \leq 0.01$, respectively).

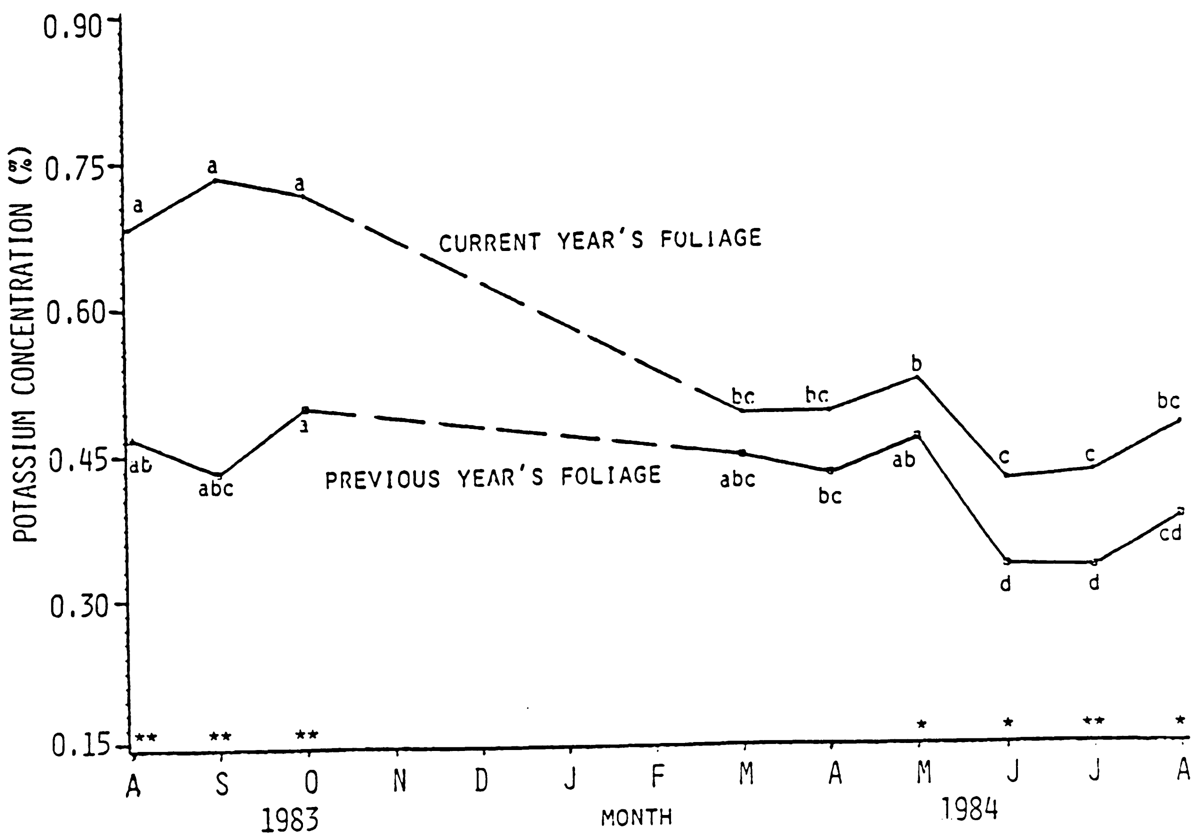

Figure 10. Seasonal K fluctuation in current and previous-year's foliage on 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga county, N.C. Months within a foliage age with dissimilar letters are significantly different ($P \leq 0.05$). Months labeled with * and ** indicate different foliage ages ($P \leq 0.05$, and $P \leq 0.01$, respectively).

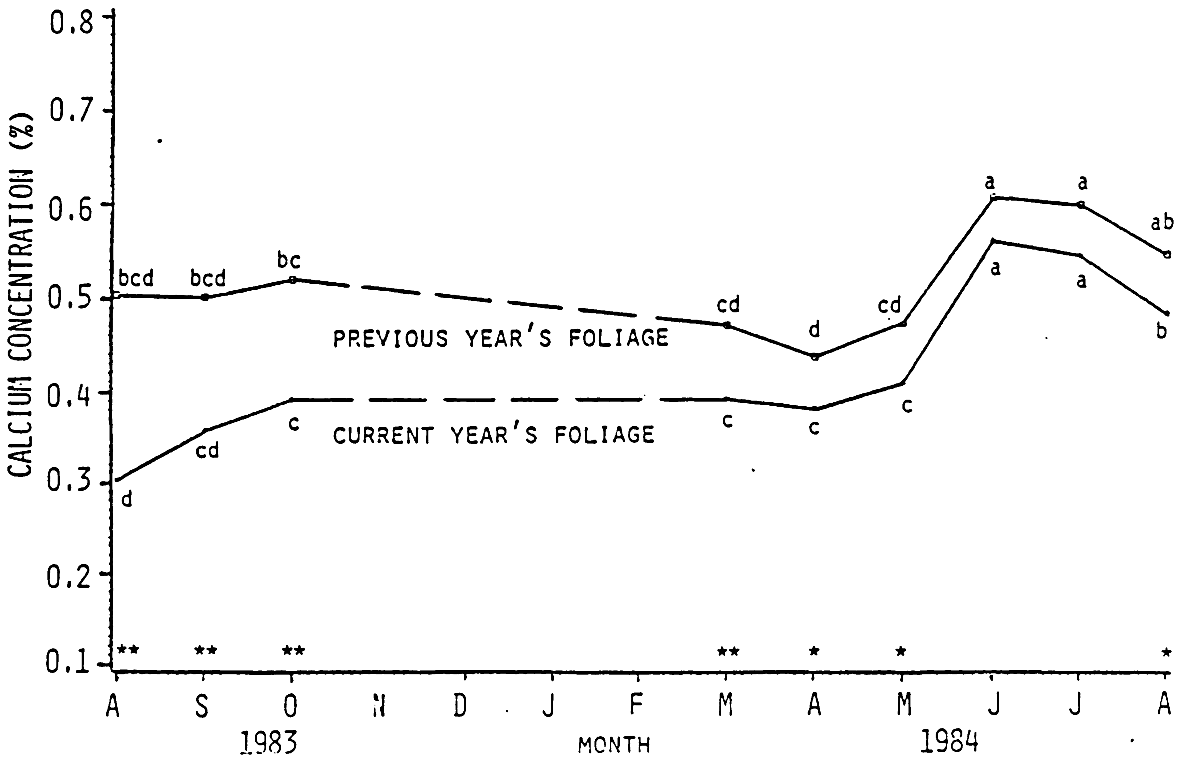

Figure 11. Seasonal Ca fluctuation in current and previous-year's foliage on 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga county, N.C. Months within a foliage age with dissimilar letters are different ($P \leq 0.05$). Months labeled with * and ** indicate different tissue ages ($P \leq 0.05$, $P \leq 0.01$, respectively).

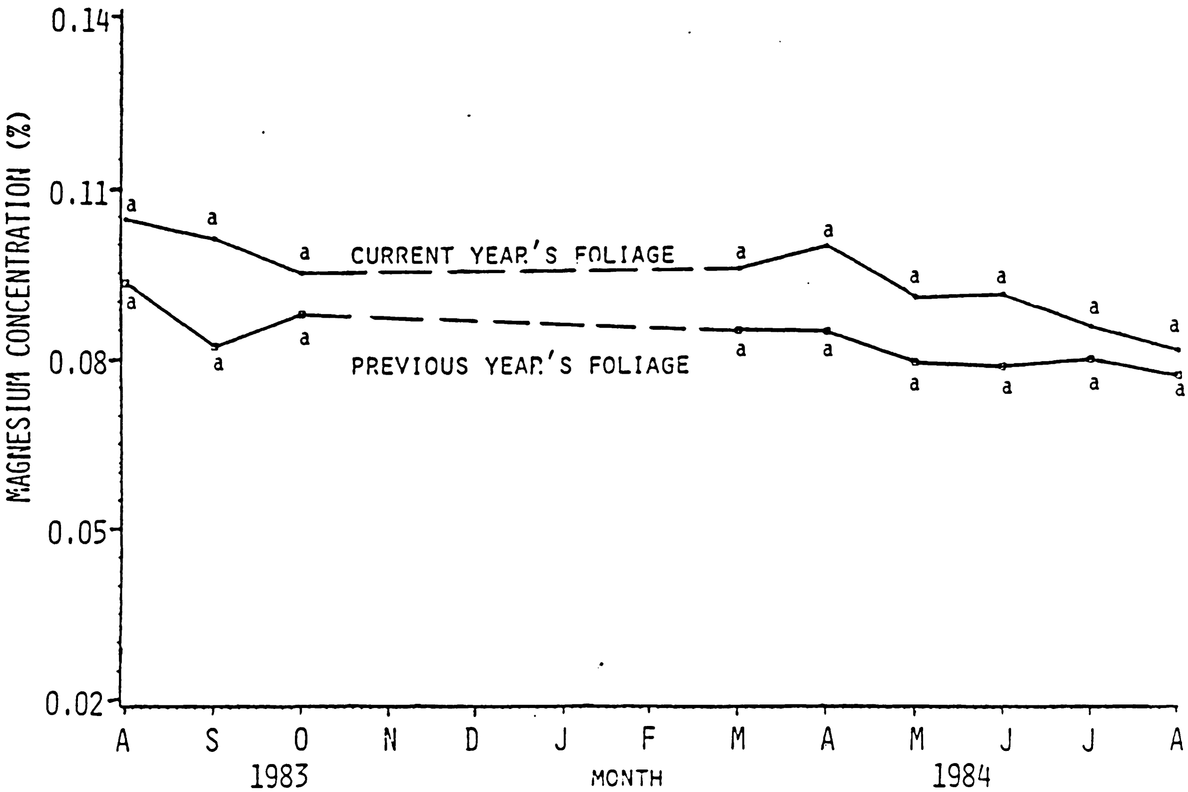

Figure 12. Seasonal Mg fluctuation in current and previous-year's foliage on 2, 4, and 7-year-old Fraser fir Christmas trees in Watauga county, N.C. Months within a foliage age with dissimilar letters are different ($P < 0.05$). Months labeled with * and ** indicate different tissue ages ($P \leq 0.05$, $P \leq 0.01$, respectively).

(comparisons based on approximated type I error rates). Nitrogen, P, and K levels were significantly higher in young tissue for all periods, except March and April where K differences were not detectable. Limited mobility was evident for Mg where higher levels existed in young tissue, yet age differences were not detectable. Nutrient immobility and accumulation are illustrated with Ca where elevated levels occurred for all months prior to the subsequent growing season.

DISCUSSION

Within-Plantation Variation

Tree to tree nutrient variation differences between the two tissue ages for Ca and Mg corresponded well to results obtained with slash pine (Pinus elliottii Engelm. var. elliottii) (Mead and Pritchett, 1974), and Monterey pine (Pinus radiata D. Don) (Mead and Will, 1976). Phosphorus and K variability contrasts between the foliage ages compared favorably to that reported for red pine (Pinus resinosa Ait.) (Comerford, 1981). Lower variation of N, P, and K in younger tissue found for slash and Monterey pine in the above mentioned studies, however, is not consistent with these results for Fraser fir. Potassium variation in current-season's tissue proved to be significantly greater, even on a relative basis (Table 1).

Variability trends for the five nutrients agreed well with those reported in the literature for Monterey, red, and slash pine and for Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco var. menziesii) (Mead and Pritchett, 1974; Berglund et. al., 1976; Mead and Will, 1976; White and Jokela, 1980; Comerford, 1981; Proebsting and Chaplin, 1983). In general, sample size estimates with identical confidence and precision tolerances were similar for N, P, and Mg, and lower for K and Ca when Fraser fir was compared to other conifers. A sample size of 19 in the two older plantation ages (Table 3) appears to yield the same level of confidence and precision for all five nutrients as would sample sizes of 23 to 35 in the species and studies reported above. This result tends to indicate that tree to tree nutrient variation for Fraser fir

Christmas trees in a plantation setting may be lower than that for Douglas-fir and other pines in plantations or natural stands. It seems reasonable to suggest that the relatively uniform site conditions frequently found in Fraser fir Christmas tree plantations may contribute to this reduced variation, although this idea was not supported by Proebsting and Chaplin (1983) for Douglas-fir.

A special feature of this study was an investigation of the plantation-age effect on tree to tree nutrient variability (Table 1). No similar investigations have been reported for any conifer species. Hence, comparison of these results with others in the literature is limited. Several assumptions are made in order to attribute the differences to age effects. First, plantations occurred on slightly different sites. Consequently, the location or site effects may be considered to be confounding the interpretation. However, if we accept that the impact of site effects on tree to tree nutrient variation are primarily imparted through the magnitude of microsite variability within a plantation which can be recognized by minor changes in local topography, then this effect was minimized through our site selection criteria. Sampling areas of about 0.4 ha within each plantation were selected that exhibited the least topographic variation and, indeed, negligible change in topographic variables was observed for the selected sampling sites. Hence, the influence of site differences on tree to tree nutrient variation in this study was considered negligible.

Seed source and cultural treatment differences between plantations are also assumed to be nonexistant or inconsequential. These assumptions are readily made for genetic variation, since one common local seed source was used for all plantings. Additionally, operational fertilization, shearing, vegetation and pest control practices have been uniform from one plantation to the next, thereby minimizing cultural treatment influences. Therefore, tree to tree nutrient variability trends and differences observed in Table 1 were attributed to plantation-age effects.

In general, nutrient variation (coefficients of variation) from tree to tree decreased with increasing plantation age. This seems plausible because newly outplanted seedlings are more subject to microsite heterogeneity; the fraction of the local soil resource utilized is very small. In contrast, trees closer to rotation age have developed extensive root systems over-lapping with adjacent trees; hence, microsite and nutritional differences may be lessened as plantation age increases. This difference means that sample sizes needed to estimate nutrient levels at a fixed precision will need to be larger for younger plantations.

In order to maintain similar precision levels, different sampling intensities are needed based on plantation age. Therefore, the following recommendation is made to achieve a precision level within 10% of the mean of the most variable nutrient. Fraser fir Christmas tree plantations 4 yr and older should be sampled with at least 20 randomly selected trees per plantation or homogeneous subsection of a plantation. Twenty-five to 30 randomly selected trees should be sampled per homogeneous area in plantations younger than 4 yr. This sampling intensity scheme should provide nutrient levels estimates for all five elements with acceptable errors ($P \leq 0.05$) within 10% of all nutrient means, except in the youngest plantations where precision levels for Mg may be slightly lower.

Within-Tree Variation

Foliar nutrient concentrations between north and south crown locations were different (Tables 5 to 9). This effect was examined in one other study dealing with a native conifer species (White, 1954). He concluded there was no differences in K levels from north, east, south, and west-facing foliage samples for 12-year-old red and white pines (Pinus strobus L.). Unfortunately, his results only examined K on four trees of each species in a plantation with an open canopy situated on soils known to be potash deficient. Analysis of other non-deficient elements in a closed, well stocked stand of these species may have revealed some aspect-related differences. In contrast, the differential shading on sheared Fraser fir Christmas trees probably influenced the metabolic activity enough to cause these nutrient concentration changes.

Although this study provides no measure of how well nutrient levels from either aspect would be related to tree performance, it seems desirable to confine sampling to one side for diagnostic purposes to minimize sampling variability. Sampling the south side of the tree may have merit. Lavender and Carmichael (1966) maintained that tissues with maximum nutrient levels more clearly defined the availability of nutrients in soils than tissues with lower or minimal levels. Results from this study demonstrated consistently higher levels for all five nutrients in foliage from the south side of tree.

Different nutrient levels among foliage age and horizontal gradients were evident for all elements regardless of the aspect or vertical position (Tables 5 to 9). The retranslocation patterns for N, P, K, and Mg, and the accumulation pattern of Ca, have been observed with other conifers including Scotch pine (Pinus sylvestris L.) (Leyton and Armson, 1955), red pine (Madgwick, 1964), black spruce [Picea mariana (Mill.) B.S.P.] (Lowry and Avard, 1969), and Monterey pine (Mead and Will, 1976). The horizontal gradient trends noted for Fraser fir are very common and apparently are more nutrient than species dependent.

The vertical distribution patterns observed for each nutrient in this study were consistent for each tissue age and corresponded with results from other species. Of the five vertical nutrient-distribution types identified by van den Driessche (1974), N, P, K, Ca, and Mg demonstrated types I, I, II, III, and III, respectively. A type I N and P distribution, indicating no vertical gradient, has been identified for red pine (Madgwick, 1964) and Monterey pine (Will, 1957) with N and for Douglas-fir (Morrison, 1970) with P. Although type II (increasing levels with higher crown positions) distributions are frequently observed for N and P, these patterns may be species specific, and patterns normally found may be modified by varying environmental conditions (van den Driessche, 1974). The type II distribution is most common for K as demonstrated for Scotch pine (Leyton and Armson, 1955), white and red pine (White, 1954), loblolly pine (Pinus taeda L.) (Wells and Metz, 1963), Monterey pine (Hall and Raupach, 1963), and Douglas-fir (Lavender and Carmichael, 1966). The characteristic K gradient in this 7-year-old Fraser fir Christmas tree plantation was most pronounced on the youngest tissue with older needles depicting more constant levels or a type I distribution (Figure 3).

Vertical trends for Ca and Mg initially indicated type V distributions or depressed levels for mid-crown positions with higher concentrations at upper and lower crown locations (Figures 4 and 5). However, the elevated nutrient contents at upper crown positions seemed to be associated with the young needles at the top of each whorl as the tree grew. In other words, these higher Ca and Mg levels appeared to be associated with an apical dominance effect since tissue from secondary terminal leaders was sampled from needles closest to the stem, while secondary laterals were sampled for other foliage ages. If these tissue ages, apparently affected by apical dominance, are disregarded, the rest of the crown exhibits a strong type III distribution for Ca and Mg that reflects higher element concentrations with lower crown positions. This typical Ca gradient has been noted in loblolly pine (Wells and Metz, 1963), Monterey pine (Will, 1957), and Douglas-fir (Lavender and Carmichael, 1966), whereas this type III Mg trend has only been observed in loblolly pine (Wells and Metz, 1963).

The effect vertical distribution can have on nutrient levels will affect selection of a standard sampling location. An upper to mid-crown sample location on current-year's tissue appears to be a viable compromise for all nutrients since the extremes from highest and lowest crown positions for K, Ca, and Mg are eliminated and the average K level is represented. Additionally, elimination of the uppermost whorl would remove the elevated Mg and Ca levels which may be influenced by an apical dominance or hormonal effect. Current-season's needles on 2- or 3-year-old whorls on the southern aspect appears to be a good standard sample location.

Seasonal Variation Study

The seasonal fluctuation in N, P, and K characterize general trends that have been observed with these mobile elements in other species. Minor peaks in N, P, and K concentrations during autumn followed by a decline or relatively stable dormant-season level has been observed for red pine (White, 1954), loblolly pine (Wells and Metz, 1963), slash pine (Mead and Pritchett, 1974), Monterey pine (Knight, 1978), and Douglas-fir (Proebsting and Chaplin, 1983). The depressed concentrations in early spring of both foliage ages is also typical, since redistribution of these nutrient pools to new tissue is activated. Significantly higher N, P, and K levels in younger tissue, regardless of sampling date, also reflects the considerable amount of retranslocation of these elements. Clearly, these results indicate that comparison of nutrient levels from older tissue to current-season's standards would yield misleading interpretations.

The non-mobile behavior of Ca described with other species is also evident with the accumulation that occurs in older tissue (Figure 11). The elevated levels in the previous season's needles for all sampling dates supports this accumulation tendency. In contrast, Mg exhibits intermediate mobility behavior with characteristics of accumulation and retranslocation apparent (Figure 12). Although younger tissue had consistently higher Mg levels, no foliage-age differences were detectable. This intermediate behavior of Mg has been shown in the other studies mentioned above.

Selection of a seasonal foliar sampling window should be based on 1) a period during which minimal temporal variation exists for all the nutrients of interest, and 2) a period corresponding to dates when identification of nutritionally different plantations is possible. Ideally, this would allow a sufficiently broad window (about 2 months), such that growers would have the opportunity to fit tissue collections into their busy schedules. Designating one collection period has obvious advantages for minimized sampling and chemical analysis work. It also allows estimation of multi-element levels on one tissue sample that may be useful when employing more advanced diagnostic techniques like DRIS (Diagnosis and Recommendation Integrated System).

Selection of one standard foliar sampling window involves a compromise with respect to optimizing the two judgement criteria for all five nutrients. Nitrogen and P plantation differences appeared to be well delineated with September and October samplings, whereas, K and Ca levels were perhaps better seperated during summer (June, July, and August) collections (Figures 6 and 7). Similarly, minimal temporal variation in P, K, Ca, and Mg occurred for fall collections (September and October), while N stability was best around March and April (Figures 8 to 12). Compromises have been necessary with other species [i.e., loblolly pine (Wells and Metz, 1963), jack pine (Lowry and Avard, 1969), slash pine (Mead and Pritchett, 1974), and Monterey pine (Mead and Will, 1976)]. However, in several cases, researchers have proposed different sampling periods depending on the indivudual nutrient. Such an approach has merit for particular studies where the sole concern is identifying plantations that differ or are deficient in a specific nutrient.

However, for general diagnostic and nutritional monitoring purposes, a single standard foliar-collection period is clearly preferable, even if minor sensitivity for one or more elements is sacrificed.

A late autumn (October and November) foliar collection window appears to represent the best compromise. Plantation N and P differences were most readily detectable during this period and adequate separation of K and Ca differences are also obtained. Minimal temporal fluctuation is also satisfied during this period, especially for P, Ca, and Mg. Delaying tissue collection until October first, after the September peaks for N and K, should remove the influence of this potentially unstable period. Although the proposed collection window includes several weeks in November were data were not available, mid November tissue sampled from the same three plantations for the tree to tree variability study indicated nutrient levels very close to those shown by the dashed lines in Figures 8 to 12. Therefore, the October-November sampling window seems to represent an optimal standard foliar collection period for Fraser fir Christmas trees. This recommended window is the same as that suggested by several investigators with other conifer species (White, 1954; Leyton and Armson, 1955; Gessel, 1962; Lavender, 1970; Everard, 1973). Additionally, such a period seems to be ideally suited for Fraser fir Christmas tree managers, since chemical analyses, diagnoses and prescriptions can be made in time for fertilizer purchases in early spring.

CONCLUSIONS

The concentrations of N, P, K, Ca, and Mg in Fraser fir foliage varies considerably with season of collection, foliage age, sample location in the crown, and from tree to tree within plantations. The greatest benefits from foliar analysis for comparative or diagnostic purposes, then, should be obtained by employing a standard foliar sampling scheme.

Suggested standard procedures for Fraser fir Christmas trees include sampling current year's needles from 2- or 3-year-old south-facing branches in October or November. To account for larger tree to tree nutrient variability in younger plantations (less than 4 yr), 25 to 30 randomly selected trees should be sampled to identify plantations that differ by at least 10% of a nutrient mean at a 95% confidence rate. Similarly, sampling intensities of 20 trees should be sampled per plantation, or homogeneous subsection, 4 yr and older to achieve comparable confidence and precision levels.

LITERATURE CITED

Berglund, J. V., A. L. Leaf, and R. E. Leonard. 1976. Red pine foliage variation and field sampling intensity. Can. J. For. Res. 6:268-280.

Comerford, N. B. 1981. Distributional gradients and variability of macroelement concentrations in the crowns of plantation grown Pinus resinosa (Ait.). Plant and Soil. 63:345-353.

Everard, J. 1973. Foliar analysis: Sampling methods, interpretation and application of the results. Quart. Jour. Forestry. 67(1):51-66.

Gessel, S. P. 1962. Progress and problems in mineral nutrition of forest trees. pp. 221-235. In: Tree growth. Ed. T. T. Kozlowski. Ronald Press Co., New York.

Hall, M. J. and M. Raupach. 1963. Foliage analyses and growth responses in Pinus radiata (D. Don) showing potassium deficiencies in eastern Victoria. Appita. 17(3):76-84.

Knight, P. J. 1978. Foliar concentrations of ten nutrients in nine Pinus radiata clones during a 15-month period. New Zea. J. For. Sci. 8(3):351-368.

Lavender, D. P. 1970. Foliar analysis and how it is used. A review. Oregon State Univ. Res. Note 52. pp. 8.

Lavender, D. P. and R. L. Carmichael. 1966. Effect of three variables on mineral concentrations in Douglas-fir needles. For. Sci. 12(4):441-446.

Leaf, A. L. 1973. Plant analysis as and aid in fertilizing forests. pp. 427-454. In: Soil testing and plant analysis. Ed. L. M. Walsh and J. D. Beaton. Soil Sci. Soc. Amer. Inc. Madison, Wisconsin. U.S.A.

Leyton, L. and K. A. Armson. 1955. Mineral conposition of the foliage in relation to the growth of Scots pine. For. Sci. 1(3):210-218.

Lowry, G. L. and P. M. Avard. 1969. Nutrient content of black spruce and jack pine needles. III. Seasonal variation and recommended sampling procedures. Pulp Pap. Res. Inst. Canada. Woodlands Papers No. 10. pp. 54.

Madgwick, H. A. I. 1964. Variations in the chemical composition of red pine (Pinus resinosa Ait.) leaves: A comparison of well-grown and poorly grown trees. Forestry. 37(1):87-94.

Mead, D. J. 1984. Diagnosis of nutrient deficiencies in plantations. pp. 259-291. In: Nutrition of plantation forests. Ed. G. D. Bowen and E. K. S. Nambiar. Acedemic Press Inc. (London) LTD.

Mead, D. J. and W. L. Pritchett. 1974. Variation of N, P, K, Ca, Mg, Mn, Zn, and Al in slash pine foliage. Commun. Soil Sci. Plant Anal. 5(4):291-301.

Mead, D. J. and G. M. Will. 1976. Seasonal and between-tree variation in the nutrient levels in Pinus radiata foliage. New Zea. J. For. Sci. 6(1):3-13.

Miller, F. W. 1966. Annual changes in foliar nitrogen, phosphorus, and potassium levels of loblolly pine (Pinus taeda L.) with site, and weather factors. Plant and Soil. 24(3):369-378.

Nelson, H. L. and T. S. Zillgitt. 1969. A Forest Atlas of the South. For. Ser., U.S. Dep. of Agric., Southern and Southeastern Forest Experiment Station, New Orleans, LA., and Asheville, NC.

Proebsting, W. M. and M. H. Chaplin. 1983. Elemental content of Douglas-fir shoot tips: Sampling and variability. Commun. Soil Sci. Plant Anal. 14(3):353-362.

Smith, W. H., G. L. Switzer, and L. E. Nelson. 1970. Development of the shoot system of young loblolly pine: I. Apical growth and nitrogen concentration. For. Sci. 16:483-490.

Van den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40(3):347-395.

Waring, R. H. and C. T. Youngberg. 1972. Evaluating forest sites for potential growth response of trees to fertilizer. Northwest Sci. 46(1):67-75.

Wells, C. G. 1965. Nutrient relationships between soils and needles of loblolly pine (Pinus taeda L.). Soil Sci. Soc. Amer. Proc. 29(5):621-624.

Wells, C. G. and L. J. Metz. 1963. Variation in nutrient content of loblolly pine needles with season, age, soil, and position on the crown. Soil Sci. Soc. Amer. Proc. 27(1):90-93.

White, D. P. 1954. Variation in the nitrogen, phosphorus, and potassium contents of pine needles with season, crown position, and sample treatment. Soil Sci. Soc. Amer. Proc. 18(3):326-330.

White, E. H. and E. J. Jokela. 1980. Variation in red pine (Pinus resinosa) foliar nutrient concentrations as influenced by sampling procedure. Can. J. For. Res. 10:233-237.

Will, G. M. 1957. Variations in the mineral content of radiata pine needles with age and position in tree crown. New Zea. J. Sci. Technol. 38(7):699-706.

PAPER NUMBER 2

A DRIS Application to Fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas Trees

Keywords:

Tissue analysis, Christmas tree quality, tree nutrition, nutritional diagnosis

(ABSTRACT)

A study developing a DRIS application to evaluate foliar nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) nutrition, was conducted on a 3-year-old Fraser fir Christmas tree plantation in Watauga county, North Carolina. DRIS norms and index equations were developed from premium grade Christmas trees for the five nutrients analyzed. In contrast to most crops where growth and yield are assessed, Fraser fir Christmas tree performance was evaluated by conventional grading procedures based on tree quality. A classification model utilizing several measured growth characteristics to predict Christmas tree grade was also investigated to objectively evaluate tree performance. Satisfactory grade-prediction results with a discriminant model were obtained yielding overall misclassification rates of 20 percent. Preliminary evaluation of DRIS performance on the 79-tree data set suggested that assessments of nutritional balance, rather than examination of individual nutrient concentrations, may be more useful for prescribing fertilizer to improve Christmas tree quality.

INTRODUCTION

Several diagnostic schemes have been used in conjunction with chemical tissue analysis to evaluate the nutritional status of crops and prescribe corrective treatments. Traditional approaches generally involve comparison of nutrient levels to "critical concentrations" or "normal ranges" that have been associated with specific levels of crop performance. Recently, a comprehensive diagnostic system, called Diagnosis and Recommendation Integrated System (DRIS), was introduced that incorporates a balanced, holistic approach to nutritional evaluations. Reduced to its simplest form, DRIS generates indices that measure the relative deficiency or sufficiency of a nutrient in terms of its deviation from an optimum level that has been established for a desirable reference population.

DRIS was originally developed by Beaufils (1971) to increase latex production of rubber trees (Hevea brasiliensis Muhl. Arg.). Since then, successful applications to many crops including corn (Zea mays L.), soybeans (Glycine max L.), wheat (Triticum aestivum L.), coastal bermuda-grass (Cynodon dactylon sp.), potatoes (Solanum tuberosum L.), sugarcane (Saccharum officinarum L.), hybrid poplar (Populus deltoides Marsh.), and monterey pine (Pinus radiata D. Don) have been made (Elwali and Gascho, 1983; Escano et al., 1981; Leech and Kim, 1981; Meldal-Johnsen and Sumner, 1980; Sumner and Beaufils, 1977; Sumner, 1977a; 1977b; 1977c; 1978; 1979; 1981; Tarpley et al., 1985; Truman and Lambert, 1981).

In plantations of high-nutrient-demanding Fraser fir Christmas trees, DRIS may represent a viable approach to addressing the problems of when to fertilize, what fertilizer to use, how much fertilizer to use and how to measure crop response. Adaptation of DRIS to this crop, however, requires that foliar nutrient status be related to Christmas tree quality rather than simple measures of growth and yield.

Fraser fir Christmas tree quality is normally evaluated by Christmas tree grade which is a subjective performance variable that integrates all quality-influencing factors. Christmas tree grade is a function of many tree-growth attributes that collectively determine grade. Ideally Christmas tree grade could be objectively evaluated using measurable tree attributes that serve as quality determinants.

The purpose of this study was to apply DRIS to a 3-year-old Fraser fir Christmas tree plantation to assess its value for making fertilizer recommendations. More specifically, the study objectives were: 1) to investigate the relationship of Fraser fir growth characteristics to Christmas tree grade; 2) to develop a discriminant model based on the growth variables for classifying individuals into Christmas tree grades; 3) to establish a preliminary set of DRIS norms and equations for high quality (premium grade) Fraser fir Christmas trees using foliar N, P, K, Ca, and Mg levels; and 4) to evaluate the performance of DRIS on the Christmas trees sampled.

METHODS

Study Area

The study area is located on Bald Mountain (lat. 36°21'N, long. 81°39'W) in Watauga county, North Carolina where plantation-grown Fraser fir Christmas trees are intensively managed on high elevation (>1310 m) grassy balds. Fraser fir Christmas tree production on these sites requires 7 to 9-year rotations after establishing plantations with 5-year-old seedlings. Cultural treatments include annual fertilization, shearing, mowing, and chemical vegetation and pest control.

The site, situated in the heart of the Blue Ridge physiographic province, has a climate that is moderated by the mountainous terrain. Adequate moisture (130 cm of mean annual total precipitation) is generally available during the relatively short growing season (approximately 140 frost free days) that exists on these mountain-tops (Nelson and Zillgitt, 1969). Average normal daily January and June temperatures are 1 and 20°C, respectively. Soils of the study area predominantly represent the Ashe (coarse-loamy, mixed, mesic, Typic Dystrochrept) and Watauga series (fine-loamy, mixed, mesic, Typic Hapludult), which are medium to moderately-heavy textured soils with many coarse fragments weathered from residuum or colluvium of high-grade metamorphic composites.

Field Sampling and Chemical Analysis

Seventy-nine trees in a 3-year-old Fraser fir Christmas tree plantation were selected in the fall of 1984 to form the data base for the study. Trees of this age were selected since they typify plantations about mid-way through an average rotation and represent an ideal growth stage to initiate evaluation of Christmas tree quality. Individual trees were chosen to represent the proportion and range of Christmas tree quality found in this age category. A wide range in site variability within the 3-year-old plantation was sampled with many topographically diverse tree locations represented. Heterogeneity in topographic areas was considered important in terms of the variability in nutrition and growth characteristics that may result.

Each tree was placed into one of three grade categories (corresponding to U.S. premium, U.S. # 1, and U.S. # 2) and all tree characteristics thought to influence tree quality were measured. These characteristics included:

1. basal diameter measured at groundline (mm).
2. current year's (1984) needle length measured from 2 and 3-year-old primordial branches on the south side of the crown (mm).
3. number of apical buds on the current year's terminal leader.
4. length of the terminal bud on the terminal leader (mm).
5. current year's (3rd growing season) terminal leader length (cm).
6. number of whorled laterals which elongated from the node of the 2nd year terminal leader.
7. number of whorled laterals which elongated from the node of the 1st year terminal leader.
8. previous year's (2nd growing season) terminal leader length (cm).
9. number of laterals which elongated from the internode of the previous year's terminal leader.

10. number of lateral buds in each successive 5 cm section on the current year's terminal leader.
11. needle color on foliage from which needle length was determined (Munsell Color System).

Current-year's needle samples were collected from each tree on 2- and 3-year-old south-facing branches on September 13, 1984. Excised shoots were returned to the lab where needle length and color determinations were made prior to drying the tissue.

Tissue handling, storage, preparation, and chemical analysis techniques were performed according to standard procedures. Foliage samples were oven-dried (65^{o} for 48 hr) and ground to pass a 20 mesh sieve. Nitrogen and P concentrations in Kjeldahl digests were colorimetrically analyzed on a Technicon Autoanalyzer via the ammonia-salicylate and phosphomolybdate complex, respectively. Determinations of K, Ca, and Mg with a Perkin Elmer (model 460) atomic absorption spectrophotometer were performed on ashed (500^{o}) subsamples extracted in 6M hydrochloric acid. Calcium and Mg were evaluated by atomic absorption using lanthanum to suppress interferences. Potassium was assessed through atomic emission using sodium to overcome ionization interferences. Means from two laboratory replicates of all nutrient estimates were obtained.

Statistical Analysis and DRIS Procedures

The relationship of tree growth attributes to Christmas tree grade was investigated with general linear model and correlation procedures in the Statistical Analysis System (Anonymous, 1985). Development of a classification model using the tree attributes as independent variables was accomplished with a canonical discriminant technique available with the same software package. Since collinearity diagnostics indicated no severe collinearity between the growth variables, all the variables were incorporated into the classification model.

Conventional DRIS methodology was employed for identification of discriminatory nutrient norms with premium grade Christmas trees designated as the reference population (Beaufils, 1973). Nutrient index equations were generated for each nutrient according to standard DRIS techniques.

RESULTS

Relation of Growth Variables to Christmas Tree Grade

The purpose of collecting the growth information on each tree was to quantify tree attributes that may be related to Christmas tree quality. Christmas tree performance is normally evaluated by grade since this variable integrates all the factors that affect Christmas tree quality. Although rules have been established by the U.S.D.A. for grading, considerable subjectivity is inherent in this performance evaluation (Anonymous, 1973). In order to obtain a more objective description of quality, the value of the measured tree attributes in a classification model to predict grade was examined.

Several variables were created from the data to evaluate their usefulness in characterizing Christmas tree quality. Since general crown density is an important grade determinant, bud and lateral density on current and previous year's terminal leaders, respectively, were included in the data set. Foliar color evaluations were standardized by using the Munsell color charts as proposed by Hamilton (1960). A color index rating based on desirable levels for Fraser fir Christmas trees was used, similar to that suggested by Turner (1966) for Douglas-fir Christmas trees. Unfortunately, color variation is this study was limited to four color cells (5GY 3/4, 5GY 4/4, 7.5GY 3/4, 7.5GY 4/4) that only varied slightly with hue, and value. Since color darkness (value differences) was considered more important than the minor change in hue, a two class color index was used on the basis of value. Foliage with the darker foliage (value = 3) was designated as class two while the lighter foliage was assigned a value of one.

Comparison of tree variable means by grade class and correlations indicated that growth measures were best related to Christmas tree grade (Table 1). The five most significantly correlated variables with grade included basal diameter, terminal leader length for the last two growing seasons, and total number of buds and laterals on those leaders. Significant correlations were also found for the number of apical buds on the current-year's terminal leader, and the number of whorled laterals which elongated at the nodes for the previous two growing seasons. Obviously, greater numbers of buds and laterals on the main stem of the tree would enhance overall crown density and, hence, was associated with premium grade Christmas trees. Although not significantly correlated, needle and terminal-bud length did exhibit mean differences between premium and lower-grade trees. Longer needles would contribute to greater foliage density and terminal bud length was considered a potential indicator of tree vigor. Trends of higher bud and leader density on the two most recent terminal leaders were also apparent for better quality trees. Even though grade 3 trees had the lowest color index, an inconsistent trend was probably due to the lack of variation in color and the use of a two-class color index.

The value of the tree variables used in a classification model to predict grade was investigated with a canonical discriminant technique (Table 2). Since placement into three classes was desired, two canonical functions were needed that yielded the two estimated parameter vectors listed in Table 2. Significant ($P \leq 0.02$) adjusted canonical correlations of 0.71 and 0.46 for the two canonical functions, were

Table 1. Comparison of tree-variable means by grade and their correlation with grade for a 3-year-old Fraser fir Christmas tree plantation in Watauga county, North Carolina.

Tree variable	Attribute means by grade			Correlation with grade
	Grade 1 (Premium)	Grade 2 (U.S.#1)	Grade 3 (U.S.#2)	
Basal diameter (mm)	44.0a[1]	36.0b	30.0c	-.629***[2]
Needle length (mm)	18.1a	16.6b	17.2ab	-.145
# of apical buds on 3rd year terminal leader	5.95a	6.19a	5.12b	-.301***
Terminal bud length (mm)	6.45a	5.75b	6.00ab	-.149
3rd year terminal leader length (cm)	51.5a	44.8a	35.2b	-.419***
Whorled laterals during 3rd year	3.23a	3.09a	2.44a	-.217*
Whorled laterals during 2nd year	3.45a	3.19a	2.80a	-.221**
2nd year terminal leader length (cm)	27.4a	21.0b	15.4c	-.485***
# of laterals on 2nd year leader	13.2a	7.03b	4.56b	-.426***
# of buds on 3rd year term. leader	38.0a	30.4b	22.4c	-.474***
Bud density on 3rd year term. leader	.734a	.691a	.666a	-.138
Lateral density on 2nd year leader	.564a	.480a	.554a	-.011
Color index	1.68a	1.72a	1.56a	-.103

[1] Means labeled with the same letters are not significantly different ($P \leq 0.05$).

[2] Correlation coefficients labeled with *, **, ***, are significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, respectively.

Table 2. Raw canonical coefficients (parameter vector) and the three discriminant equations used to classify Fraser fir Christmas trees in a 3-year-old plantation into one of the three grade (quality) categories.

$$\underline{l}_1 = \begin{bmatrix} 0.10401 \\ -0.10084 \\ 0.31461 \\ 0.21364 \\ -0.06013 \\ 0.21972 \\ 0.01080 \\ 0.01794 \\ 0.02630 \\ 0.11195 \\ -2.80072 \\ -0.29756 \\ 0.22749 \end{bmatrix} \qquad \underline{l}_2 = \begin{bmatrix} -0.04525 \\ 0.42157 \\ -0.92298 \\ 0.29669 \\ -0.00738 \\ 0.06888 \\ 0.56599 \\ -0.03924 \\ 0.03513 \\ 0.06255 \\ 0.54740 \\ 0.86786 \\ -0.81220 \end{bmatrix}$$

Discriminant distance functions for grades 1, 2, and 3

$$D_1 = [\underline{l}_1'(\underline{x} - \bar{\underline{x}}_1)]^2 + [\underline{l}_2'(\underline{x} - \bar{\underline{x}}_1)]^2$$

$$D_2 = [\underline{l}_1'(\underline{x} - \bar{\underline{x}}_2)]^2 + [\underline{l}_2'(\underline{x} - \bar{\underline{x}}_2)]^2$$

$$D_3 = [\underline{l}_1'(\underline{x} - \bar{\underline{x}}_3)]^2 + [\underline{l}_2'(\underline{x} - \bar{\underline{x}}_3)]^2$$

where:

D_1, D_2, and D_3 are the square distances from the centroids of grades 1, 2, and 3 respectively

$\underline{l}_1'$ and $\underline{l}_2'$ are the transposes of the canonical coefficient vectors listed above

$\underline{x}$ is the vector of tree variables in the order listed in table 1 for the tree being classified

$\bar{\underline{x}}_1$, $\bar{\underline{x}}_2$, and $\bar{\underline{x}}_3$ are the vectors of tree variable means in table 1 for grades 1, 2, and 3, respectively generated for this data set. For any observation (tree), the classification approach requires the evaluation of three square distance equations each measuring the relative proximity to the centroid of each class. The classification rule designates the grade of x to j where $D_j = \min (D_1, D_2, D_3)$.

Model evaluation is given by the classification table where the number of observations and percentage correctly and incorrectly classified are listed (Table 3). For example, of the 32 trees evaluated as grade 2, 26 were correctly classified while 3 trees were misclassified into grades 1 and 3, respectively. Overall, the model correctly classified 63 out of 79 trees or 80 percent of the observations.

Development of DRIS Norms and Equations

Following to DRIS methodology, the sample population was divided into desirable (grade 1) and undesirable (grades 2 and 3) groups (Table 4) for comparison of nutrient-expression (ratios) means and variances (Beaufils, 1973). Comparison of means and variances between the two groups was accomplished via the T-test and F-test, respectively. Only nutrient expressions involving Mg, except the Mg/Ca ratio, had significantly different means between the two groups. The best Christmas tree performance was associated with least Mg uptake, whereas, the opposite was evident with K. Significant variance ratios were found for seven of the ten nutrient ratios involving all combinations of the five nutrients.

Identification of DRIS norms generally requires that significant variance ratios exist for the two groups. In this study, three Ca

Table 3. Classification table for the discriminant model used to predict Fraser fir Christmas tree grade in a 3-year-old plantation.

From grade	Number of observations and percents classified into each grade 1	2	3	Total
1	17	5	0	22
	77.3	22.7	0	100.0
2	3	26	3	32
	9.4	81.2	9.4	100.0
3	2	3	20	25
	8.0	12.0	80.0	100.0
Total	22	34	23	
percent	27.9	43.0	29.1	

Overall correct classification rate = 79.5%

Table 4. Comparison of means and variances for nutrient expressions between premium (pop. B) and nonpremium (pop. A) grade Fraser fir Christmas trees in a 3-year-old plantation. Sample sizes for for populations A and B are 57 and 22, respectively.

Nutrient expression	Pop A (low grade)		Pop B (premium grade)		Variance ratio
	Mean	Variance (Sa^2)	Mean	Variance (Sb^2)	Sa^2/Sb^2
N (%)	2.425a[1]	0.0539	2.478a	0.0363	1.48
P (%)	0.227a	0.0013	0.224a	0.0009	1.52
K (%)	0.908a	0.0164	0.942a	0.0175	.94
Ca (%)	0.379a	0.0052	0.361a	0.0052	1.00
Mg (%)	0.097a	0.0003	0.085b	0.0002	1.94*[2]
N/K	2.714a	0.1692	2.659a	0.0649	2.61**
P/N	0.094a	0.00021	0.090a	0.00009	2.44**
P/K	0.253a	0.0020	0.240a	0.0009	2.34**
Ca/N	0.156a	0.0008	0.146a	0.0009	.89
Ca/P	1.705a	0.1695	1.616a	0.0790	2.15*
Ca/K	0.426a	0.0111	0.391a	0.0100	1.11
Mg/N	0.040a	0.00006	0.034b	0.00002	2.50**
Mg/P	0.440a	0.0109	0.383b	0.0039	2.76**
Mg/K	0.110a	0.0008	0.091b	0.0002	3.52***
Mg/Ca	0.262a	0.0022	0.242a	0.0024	.92

1 Nutrient expression means identified by the same letters are not different ($P \leq 0.05$).

2 Variance ratios labeled with *, **, ***, indicate different variances at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, respectively.

ratios did not fit this criteria. Others have shown that including nutrient ratios with nonsignificant variance differences in DRIS index equations may reduce the sensitivity for a nutrient, yet a more balanced diagnosis can be obtained (Beaufils and Sumner, 1976). For this reason, all nutrient ratios were retained for index equation development. A comparison of ratio means and coefficients of variation (CV) for the set of ten ratios is given in Table 5. The paired means and CV's for the nutrient ratios in the premium grade group (DRIS norms) were kept for use in nutrient index equations. However, all ratios, except Ca/N, Ca/K, and Mg/Ca, were considered discriminatory DRIS norms due to their significant variance ratios.

A DRIS index equation was developed for each nutrient involving functional components with each of the other four nutrients (Table 6). The formulation of these equations and an example calculation of an intermediate function is given (Beaufils, 1973).

Since the objective of this study was to develop and establish a preliminary DRIS application with Fraser fir Christmas trees, independent diagnoses and validation of DRIS performance are not discussed. These secondary stages are the subject of continued studies with a fertilizer trial and operational validation procedures.

Initial performance of the DRIS norms and equations was investigated by examining some summary statistics on nutrient indices for the same premium and nonpremium groups of trees (Table 7). Note that none of the nutrient index means for the premium population deviate from zero by more than one, whereas, none are within this limit for the nonpremium grade Christmas trees. This supports the concept of nutritional balance

Table 5. Comparison of means and coefficients of variation (CV) for nutrient ratios between nonpremium and premium grade Fraser fir Christmas trees in a 3-year-old plantation. Mean and CV of ratios for the premium grade population are designated DRIS norms.

Nutrient ratio	Nonpremium grade trees		Premium grade trees	
	Mean	CV (%)	Mean	CV (%)
N/K	2.714	15.2	2.659	9.6
P/N	0.094	15.5	0.090	10.3
P/K	0.253	17.8	0.240	12.3
Ca/N	0.156	17.9	0.146	20.8
Ca/P	1.705	24.1	1.616	17.4
Ca/K	0.426	24.8	0.391	25.6
Mg/N	0.040	18.4	0.034	13.7
Mg/P	0.440	23.7	0.383	16.4
Mg/K	0.110	26.1	0.091	16.8
Mg/Ca	0.262	17.8	0.242	20.4

Table 6. DRIS index equations for assessing the relative N, P, K, Ca, and Mg status in 3-year-old Fraser fir Christmas tree plantations.

N index = [f(N/K) - f(P/N) - f(Ca/N) - f(Mg/N)]/4

P index = [f(P/N) + f(P/K) - f(Ca/P) - f(Mg/P)]/4

K index = -[f(N/K) + f(P/K) + f(Ca/K) + f(Mg/K)]/4

Ca index = [f(Ca/N) + f(Ca/P) + f(Ca/K) - f(Mg/Ca)]/4

Mg index = [f(Mg/N) + f(Mg/P) + f(Mg/K) + f(Mg/Ca)]/4

An example of calculating an intermediate function is:

$$f(A/B) = 100[\frac{A/B}{a/b} - 1] * (10/CV) \quad \text{if } A/B > a/b$$

$$f(A/B) = 100[1 - \frac{a/b}{A/B}] * (10/CV) \quad \text{if } A/B < a/b$$

where:

A/B is the foliar nutrient ratio of 2 nutrients in an individual tree or plantation

a/b is the mean nutrient ratio of 2 nutrients in the premium grade population

CV is the coefficient of variation of a/b in the premium grade population

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Table 7. Comparison of summary statistics on nutrient indices and the sum of the absolute value of the five indices for the nonpremium and premium grade Fraser fir Christmas tree samples.

Nutrient index	Nonpremium grade trees				Premium grade trees			
	Mean	Minimum	Maximum	Range	Mean	Minimum	Maximum	Range
N index	-4.2	-23.6	15.7	39.3	0.4	-13.9	14.5	28.4
P index	-1.1	-34.6	27.7	62.3	0.3	-9.6	20.4	30.0
K index	-4.8	-41.0	25.4	66.4	0.8	-19.5	24.3	43.8
Ca index	1.2	-21.9	28.8	50.7	-.6	-28.7	26.3	55.0
Mg index	8.9	-36.6	46.7	83.3	-.9	-19.3	24.1	43.4
Sum of indices	50.9[1]	15.7	135.1	119.4	31.4	5.2	93.4	88.2

[1] Sum of the absolute value of all the nutrient indices can be used as a measure of the magnitude of nutritional imbalance.

required for increased crop performance. Also observe that the minimum, maximum, and range for all nutrient indices, except Ca, were greater in the nonpremium group. The apparent anomaly for Ca is due to the fact that three of the four ratios in the Ca index equation actually had slightly greater variation in the premium grade trees.

The sum of the nutrient indices, irrespective of sign, indicates greater nutritional imbalance is associated with the lower grade trees (Table 7). The mean sum was 31.4 and 50.9 for the premium and nonpremium groups, respectively. Contrasting the minimum, maximum, and range of this sum between these two groups also supports this nutrient balance concept.

DISCUSSION

Christmas Tree Quality Evaluation

The strong relationship of growth and bud-frequency variables to Fraser fir Christmas tree grade was expected. The primary factors considered during grading were crown shape and fullness and general crown or foliage density. Investigation of these relationships on 3-year-old plantations across a wider range of sites and management practices would probably indicate even stronger trends, since greater variation in all growth variables would undoubtedly be encountered.

Prediction of Christmas tree grade with a discriminant model using the measured tree attributes was successful. Although an overall classification rate of 80 percent may be considered good, in some applications, such as final grading before harvest, misclassifying one out of five trees would not be satisfactory. Obviously, incorporating other information useful in describing Christmas tree grade into the discrimimant model could decrease the misclassification rate; however, this may require measurement of many more tree attributes and from a practical standpoint be less valuable.

Despite these limitations, the discriminant model performed quite well when the nature of the classification problem is considered. Applying conventional grading criteria designed for harvest-age Christmas trees to a young 3-year-old plantation is difficult at best. Considerable growth and improvement in crown shape and density will occur for all grade trees in this young plantation before harvest. The shearing regime that has and will be applied to each tree is a very important determinant of ultimate tree grade. Although potentially difficult to measure, variables related to shearing technique may be very useful in a classification model. As noted earlier, consideration for the trees potentially fitting into adjacent grades reduced the overall true misclassification rate to 11 percent.

Two potential limitations of this discriminant model are 1) the age dependency of many tree variables (especially growth attributes); the model would not be applicable for grade prediction in younger or older plantation ages, and 2) the prediction of Christmas tree grade would be most accurate for similar populations where tree variables occur within the range observed in this study. Plantations on other sites with different genetic sources and management practices may have a slightly different optimum combination of tree variables in terms of their association with Christmas tree grade. Despite these possible limitations, use of the model in similar populations should provide a reasonable quantitative and objective means of predicting Christmas tree grade. Unfortunately, no similar classification approaches have been reported in the literature and so comparison of these results is not possible.

DRIS Application

In contrast with traditional DRIS applications where crop performance is measured by a continuous variable like m^3/ha, Mg/ha, or m/yr, Fraser fir Christmas tree performance in this study was evaluated by a three class variable of Christmas tree grade. According to DRIS theory, crop quality (not necessarily yield or growth) may be used in a

DRIS application to maximize this performance variable (Beaufils, 1973). In this study, discriminatory DRIS norms were successfully identified and related to Fraser fir Christmas tree grade.

Comparison of nutrient expressions between premium and nonpremium grade Christmas trees revealed nutritional differences in terms of means and variability. In contrast to a critical-level approach where higher nutrient levels would be associated with either decreased deficiency or increased sufficiency, this study showed that lower foliar Mg levels corresponded with improved Christmas tree performance (Table 4). In fact, three out of the five nutrients examined (P, Ca, and Mg) had lower mean concentrations in premium versus nonpremium trees. This tends to indicate that nutritional balance is more important than absolute levels of individual nutrients. Further support for this concept is given by the seven discriminatory nutrient ratios whose significantly lower variation around the optimum ratio was associated with premium grade Christmas tree performance.

Five nutrient index equations, each including four functional components, were developed to evaluate the relative nutrient status in Fraser fir foliage (Table 6). Since each index equation involves a function relating a given nutrient to each of the other four nutrients, the indices generated are comparable functions of Christmas tree quality (Beaufils, 1971). The sum of the five indices for any observation must equal zero because each equation only measures the relative deviation from the optimum. Comparison of the indices then allows a ranking of the relative adequacy or deficiency of each nutrient.

A DRIS evaluation of grade 2 and 3 trees suggests that overall nutrient limitations occur in the order K, N, and P, while Ca and Mg are adequate (Table 7). Comparison of the minimum, maximum, and range of each nutrient index between the premium and nonpremium groups shows considerably greater index variation for the poorer quality trees, with the exception of Ca. Similar variation in Ca is due to the use of three Ca ratios (Ca/N, Ca/K, and Mg/Ca) in the Ca index equation that had equivalent or greater variation in the premium grade population. This result indicates that Ca nutrition, compared to the other nutrients, is relatively unimportant in determining Christmas tree quality.

Although independent tests of the preliminary DRIS norms in plantation diagnoses were not presented, further studies on validation and calibration with fertilizer trials and operational diagnoses are being conducted. Identification of discriminatory nutrient ratios and levels of significance in F-tests are known to be dependent on sample sizes in both desirable and undesirable populations and employing appropriate measures of crop performance (Beaufils, 1973; Jones, 1981). Detection of seven discriminatory norms here with only 22 and 57 observations in the two groups, respectively, suggests that considerable potential exists for successful DRIS evaluations of Fraser fir Christmas trees. Also, a performance variable like Christmas tree grade appears to serve quite well with advanced diagnostic systems like DRIS. Potential problems can arise, however, when Christmas tree quality evaluations are inconsistent from grader to grader. In this regard, using more specific standardized grading criteria and/or application of classification models, like the one presented, should provide the invariant grading mechanism needed.

CONCLUSIONS

Fraser fir Christmas tree quality as evaluated by conventional 3-class grade categories, was related to various measurable tree attributes. Eight out of 13 tree characteristic variables had significantly different levels by grade or were significantly correlated with grade. Stem diameter and leader growth, bud and lateral frequency variables were the attributes best related to Christmas tree grade.

Grade classification of individual trees, with the thirteen tree attributes included in a canonical discriminant model as Christmas tree quality determinants, was accomplished with considerable success. Significant canonical correlations for the two canonical functions were obtained with this discriminant application. All grades considered, a correct classification rate of 80 percent was achieved. Accounting for trees that were originally noted to potentially fit adjacent grades resulted in an improved correct classification rate of 89 percent. Fraser fir Christmas trees in similar populations may be objectively graded by the discriminant model with satisfactory performance subject to the limitations discussed.

Successful development of DRIS norms and nutrient index equations for N, P, K, Ca, and Mg, indicated Fraser fir Christmas tree grade had great utility as a quality performance variable in this DRIS application. Seven out of ten ratios relating the five nutrients to each other were identified as discriminatory DRIS norms in this 3-year-old plantation. Evaluation of several summary statistics on nutrient indices for the premium and nonpremium tree groups suggested greater variation and nutritional imbalance was associated with the poorer quality Christmas trees. Although preliminary observations indicate considerable promise for the use of DRIS with Fraser fir Christmas trees, greatest diagnostic benefits will be realized through continued refinement, validation, and calibration efforts.

LITERATURE CITED

Anonymous. 1973. United States Standards for Grades of Christmas Trees. U.S. Dep. of Agric., Food Safety and Quality Service, Wash. D.C.

Anonymous. 1985. SAS User's Guide: Statistics. Version 5 Edition. SAS Institute Inc., Cary N.C.

Beaufils, E. R. 1971. Physiological diagnosis - A guide for improving maize production based on principles developed for rubber trees. Fert. Soc. of South Africa J. 1:1-31.

Beaufils, E. R. 1973. Diagnosis and recommendation integrated system (DRIS). A general scheme for experimentation and calibration based on principles developed from research in plant nutrition. Soil Sci. Bul. 1, Univ. of Natal, South Africa.

Beaufils, E. R. and M. E. Sumner. 1976. Application of the DRIS approach for calibrating soil and plant factors in their affects on yield of sugarcane. Proc. S. Afr. Sugar Tech. Ass. 30:118-124.

Elwali, A. M. O. and C. J. Gascho. 1983. Sugarcane response to P, K, and DRIS corrective treatments on Florida Histosols. Agron. J. 75:79-83.

Escano, C. R., C. A. Jones, and G. Uehara. 1981b. Nutrient diagnosis in corn grown on Hydric Drystrandepts: II. Comparison of two systems of tissue diagnosis. Soil Sci. Soc. of Am. J. 45:1140-1144.

Hamilton, L. S. 1960. Color standardization for foliage description in forestry. J. Forestry. 58:23-25.

Jones, C. A. 1981. Proposed modifications of the Diagnosis and Recommendation Integrated System (DRIS) for interpreting plant analyses. Commun. Soil Sci. Plant Anal. 12(8):785-794.

Leech, R. H. and Y. T. Kim. 1981. Foliar analysis and DRIS as a guide to fertilizer amendments in poplar plantations. The For. Chron. 57(1):17-21.

Meldal-Johnsen, A. and M. E. Sumner. 1980. Foliar diagnostic norms for potatoes. J. of Plant Nutrition. 2(5):569-576.

Nelson, H. L. and T. S. Zillgitt. 1969. A Forest Atlas of the South. For. Ser., U.S. Dep. of Agric., Southern and Southeastern Forest Experiment Station, New Orleans, LA. and Asheville, NC.

Sumner, M. E. 1977a. Use of the DRIS system to foliar diagnosis of crops at high yield levels. Commun. Soil Sci. Plant Anal. 8(3):251-268.

Sumner, M. E. 1977b. Preliminary N, P, and K foliar diagnostic norms for soybeans. Agron. J. 69:226-230.

Sumner, M. E. 1977c. Preliminary N, P, K foliar diagnostic norms for wheat. Commun. Soil Sci. Plant Anal. 8(2):149-167.

Sumner, M. E. 1978. Interpretation of nutrient ratios in plant tissue. Commun. Soil Sci. Plant Anal. 9(4):335-345.

Sumner, M. E. 1979. Interpretation of foliar analyses for diagnostic purposes. Agron. J. 71:343-348.

Sumner, M. E. 1981. Diagnosing the sulfur requirements of corn and wheat using foliar analysis. Soil Sci. Soc. of Amer. J. 45:87-90.

Sumner, M. E. and E. R. Beaufils. 1977. Application of Beaufils' diagnosis and recommendation integrated system (DRIS) to sugarcane - final report. Dept. of Soil Sci. and Agrometeorology, Univ. of Natal, South Africa.

Tarpley, M. L., D. L. Robinson, B. K. Gustavson, and M. M. Eichhorn, Jr. 1985. The DRIS for interpretation of coastal bermudagrass analysis. Commun. Soil Sci. Plant Anal. 16(12):1335-1348.

Truman, R. and M. J. Lambert. 1981. The use of DRIS indices to determine the balance between nitrogen, phosphorus and sulfur in Pinus radiata foliage. Forestry Council Research Working Groups I and III, Forestry Commission of N. S. W.

Turner, D. O. 1966. Color and growth of Douglas-fir Christmas trees as affected by fertilizer application. Soil Sci. Soc. Amer. Proc. 30:792-795.

SUMMARY AND CONCLUSIONS

Results from the three studies characterizing foliar nutrient variation patterns indicated considerable variability in N, P, K, Ca, and Mg existed, within Fraser fir Christmas tree plantations, within the tree crown, and due to normal seasonal trends. Tree to tree variability trends revealed increasing nutrient variation for nutrients in the order N, P, K, Ca, and Mg. Trends of decreased variation for all nutrients with increased plantation age were also apparent. Aspect differences (north versus south) and horizontal gradients (different tissue ages) were evident for each of the nutrients in the within-tree variation study. Vertical nutrient distribution patterns found for N and P were constant, while K, Ca, and Mg exhibited distinctive vertical gradients. Seasonal nutrient fluctuation typified variation patterns identified for mobile elements (N, P, K, and to some extent Mg) and non-mobile elements (Ca). Overall, the results from these studies were in good agreement with those observed with other conifer species.

Interpretation of the results within a management context, led to the formulation of recommended standard foliar sampling practices for Fraser fir Christmas tree plantation managers. Suggested standard practices include sampling current-season's needles from 2- or 3-year-old south-facing branches in October or November. Sampling intensities recommended in younger plantations (less than 4 yr) involved sampling 25 to 30 randomly selected trees in each plantation or homogeneous subsection designated as a management unit. Similarly, sample size requirements in older plantations (4 yr and older), for comparable confidence levels and error tolerances, involved sampling only 20 trees per plantation.

DRIS norms were developed for a 3-year-old plantation in a study where the focus was to relate Fraser fir Christmas tree performance to a foliar nutrient status. Seven out of ten ratios combining the five nutrients to each other were found to be discriminatory, by conventional DRIS methodology, when premium grade Christmas trees were designated as the desirable population. Application of DRIS index equations, including all ten nutrient norms, to the premium and nonpremium grade trees, indicated that greater nutrient imbalances were associated with the poorer quality Christmas trees. These observations supported the concept inherent in DRIS that greater nutritional balance was required to increase the chances of obtaining better crop performance. Potential problems in the consistent evaluation (grading) of Christmas tree performance were addressed through developing a classification model, based on measured tree attributes, to predict Christmas tree grade. Considerable success was obtained with a canonical discriminant approach were an overall correct classification rate of about 80 percent could be expected. Possible limitations of the model were noted for other aged plantations and classification in plantations where different genetic sources and management practices were employed.

LITERATURE CITED

Beaufils, E. R. 1971. Physiological diagnosis - A guide for improving maize production based on principles developed for rubber trees. Fert. Soc. of South Africa J. 1:1-31.

Beaufils, E. R. 1973. Diagnosis and recommendation integrated system (DRIS). A general scheme for experimentation and calibration based on principles developed from research in plant nutrition. Soil Sci. Bul. 1, Univ. of Natal, South Africa.

Berglund, J. V., A. L. Leaf, and R. E. Leonard. 1976. Red pine foliage variation and field sampling intensity. Can. J. For. Res. 6:268-280.

Comerford, N. B. 1981. Distributional gradients and variability of macroelement concentrations in the crowns of plantation grown Pinus resinosa (Ait.). Plant and Soil. 63:345-353.

Elwali, A. M. O. and C. J. Gascho. 1983. Sugarcane response to P, K, and DRIS corrective treatments on Florida Histosols. Agron. J. 75:79-83.

Escano, C. R., C. A. Jones, and G. Uehara. 1981a. Nutrient diagnosis in corn grown on Hydric Drystandepts: I. Optimum tissue nutrient concentrations. Soil Sci. Soc. of Am. J. 45:1135-1139.

Escano, C. R., C. A. Jones, and G. Uehara. 1981b. Nutrient diagnosis in corn grown on Hydric Drystrandepts: II. Comparison of two systems of tissue diagnosis. Soil Sci. Soc. of Am. J. 45:1140-1144.

Gagnon, J. D. 1964. Relationship between site index and foliage nitrogen at two crown levels for mature black spruce. For. Chron. 40(2):169-174.

Gascho, G. J. and A. M. O. Elwali. 1979. Tissue testing of Florida sugarcane. The Sugar J. 42:15-16.

Hall, M. J. and M. Raupach. 1963. Foliage analyses and growth responses in Pinus radiata (D. Don) showing potassium deficiencies in eastern Victoria. Appita. 17(3):76-84.

Jones, C. A. 1981. Proposed modifications of the Diagnosis and Recommendation Integrated System (DRIS) for interpreting plant analyses. Commun. Soil Sci. Plant Anal. 12(8):785-794.

Jones, C. A. and J. E. Bowen. 1981. Comparative DRIS and crop log diagnosis of sugarcane tissue analyses. Agron. J. 73:941-943.

Kelling, K. A., T. Erikson, and E. E. Schulte. 1981. DRIS - A new approach to alfalfa. p. 55-70. Proc. of Annual Meeting of the Certified Alfalfa Seed Council - Alfalfa Forum. Madison, Wis. March, 1981.

Knight, P. J. 1978. Foliar concentrations of ten nutrients in nine *Pinus radiata* clones during a 15-month period. New Zea. J. For. Sci. 8(3):351-368.

Lavender, D. P. 1970. Foliar analysis and how it is used. A review. Oregon State Univ. Res. Note 52. pp. 8.

Lavender, D. P. and R. L. Carmichael. 1966. Effect of three variables on mineral concentrations in Douglas-fir needles. For. Sci. 12(4):441-446.

Leaf, A. L. 1973. Plant analysis as and aid in fertilizing forests. pp. 427-454. In: Soil testing and plant analysis. Ed. L. M. Walsh and J. D. Beaton. Soil Sci. Soc. Amer. Inc. Madison, Wisconsin. U.S.A.

Leech, R. H. and Y. T. Kim. 1981. Foliar analysis and DRIS as a guide to fertilizer amendments in poplar plantations. The For. Chron. 57(1):17-21.

Leyton, L. and K. A. Armson. 1955. Mineral conposition of the foliage in relation to the growth of Scots pine. For. Sci. 1(3):210-218.

Lowry, G. L. and P. M. Avard. 1965. Nutrient content of black spruce needles. I. Variation due to crown position and needle age. Pulp pap. Res. Inst. Canada. Tech. Rept. 425. pp. 21.

Lowry, G. L. and P. M. Avard. 1969. Nutrient content of black spruce and jack pine needles. III. Seasonal variation and recommended sampling procedures. Pulp Pap. Res. Inst. Canada. Woodlands Papers No. 10. pp. 54.

Madgwick, H. A. I. 1964. Variations in the chemical composition of red pine (*Pinus resinosa* Ait.) leaves: A comparison of well-grown and poorly grown trees. Forestry. 37(1):87-94.

Mead, D. J. 1984. Diagnosis of nutrient deficiencies in plantations. pp. 259-291. In: Nutrition of plantation forests. Ed. G. D. Bowen and E. K. S. Nambiar. Acedemic Press Inc. (London) LTD.

Mead, D. J. and W. L. Pritchett. 1974. Variation of N, P, K, Ca, Mg, Mn, Zn, and Al in slash pine foliage. Commun. Soil Sci. Plant Anal. 5(4):291-301.

Mead, D. J. and G. M. Will. 1976. Seasonal and between-tree variation in the nutrient levels in *Pinus radiata* foliage. New Zea. J. For. Sci. 6(1):3-13.

Meldal-Johnsen, A. and M. E. Sumner. 1980. Foliar diagnostic norms for potatoes. J. of Plant Nutrition. 2(5):569-576.

Miller, F. W. 1966. Annual changes in foliar nitrogen, phosphorus, and potassium levels of loblolly pine (Pinus taeda L.) with site, and weather factors. Plant and Soil. 24(3):369-378.

Morrow, L. D. and V. R. Timmer. 1981. Intraseasonal growth and nutrient composition of jack pine needles following fertilization. Can. J. For. Res. 11:696-702.

Proebsting, W. M. and M. H. Chaplin. 1983. Elemental content of Douglas-fir shoot tips: Sampling and variability. Commun. Soil Sci. Plant Anal. 14(3):353-362.

Smith, W. H., G. L. Switzer, and L. E. Nelson. 1970. Development of the shoot system of young loblolly pine: I. Apical growth and nitrogen concentration. For. Sci. 16:483-490.

Sumner, M. E. and E. R. Beaufils. 1977. Application of Beaufils' diagnosis and recommendation integrated system (DRIS) to sugarcane - final report. Dept. of Soil Sci. and Agrometeorology, Univ. of Natal, South Africa.

Sumner, M. E. 1977a. Effect of corn leaf sampled on N, P, K, Ca and Mg content and calculated DRIS indices. Commun. Soil Sci. Plant Anal. 8(3):269-280.

Sumner, M. E. 1977b. Use of the DRIS system to foliar diagnosis of crops at high yield levels. Commun. Soil Sci. Plant Anal. 8(3):251-268.

Sumner, M. E. 1977c. Preliminary N, P, and K foliar diagnostic norms for soybeans. Agron. J. 69:226-230.

Sumner, M. E. 1977d. Preliminary N, P, K foliar diagnostic norms for wheat. Commun. Soil Sci. Plant Anal. 8(2):149-167.

Sumner, M. E. 1978. Interpretation of nutrient ratios in plant tissue. Commun. Soil Sci. Plant Anal. 9(4):335-345.

Sumner, M. E. 1979. Interpretation of foliar analyses for diagnostic purposes. Agron. J. 71:343-348.

Sumner, M. E. 1981. Diagnosing the sulfur requirements of corn and wheat using foliar analysis. Soil Sci. Soc. of Amer. J. 45:87-90.

Swan, H. S. D. 1962. The mineral nutrition of the Grand'mere plantations. Pulp Pap. Res. Inst. Canada. Tech. Rept. Series 276. Woodld. Res. Index 131. pp. 14.

Tarpley, M. L., D. L. Robinson, B. K. Gustavson, and M. M. Eichhorn, Jr. 1985. The DRIS for interpretation of coastal bermudagrass analysis. Commun. Soil Sci. Plant Anal. 16(12):1335-1348.

Truman, R. and M. J. Lambert. 1981. The use of DRIS indices to determine the balance between nitrogen, phosphorus and sulfur in Pinus radiata foliage. Forestry Council Research Working Groups I and III, Forestry Commission of N. S. W.

Van den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40(3):347-395.

Waring, R. H. and C. T. Youngberg. 1972. Evaluating forest sites for potential growth response of trees to fertilizer. Northwest Sci. 46(1):67-75.

Wells, C. G. 1965. Nutrient relationships between soils and needles of loblolly pine (Pinus taeda L.). Soil Sci. Soc. Amer. Proc. 29(5):621-624.

Wells, C. G. and L. J. Metz. 1963. Variation in nutrient content loblolly pine needles with season, age, soil, and position on the crown. Soil Sci. Soc. Amer. Proc. 27(1):90-93.

White, D. P. 1954. Variation in the nitrogen, phosphorus, and potassium contents of pine needles with season, crown position, and sample treatment. Soil Sci. Soc. Amer. Proc. 18(3):326-330.

White, E. H. and E. J. Jokela. 1980. Variation in red pine (Pinus resinosa foliar nutrient concentrations as influenced by sampling procedure. Can. J. For. Res. 10:233-237.

Will, G. M. 1957. Variations in the mineral content of radiata pine needles with age and position in tree crown. New Zea. J. Sci. Technol. 38(7):699-706.

Wright, T. W. and G. M. Will. 1958. The nutrient contents of Scots and Corsican pines growing on sand dunes. Forestry. 31(1):13-25.

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