Applying the Diagnosis and Recommendation Integrated System (DRIS) to Fraser Fir Christmas Trees

by

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Forestry

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May, 1988

Blacksburg, Virginia

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(ABSTRACT)

The process of diagnosing the foliar nutrient status of Fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas trees and prescribing fertilizers is not well understood. Agricultural researchers have established critical yield levels for agronomic crops that are objective measures of crop quality and have associated these yields with nutrient status; however, Christmas tree quality is subjective and not well associated with nutrient status. A nutrient-sensitive tree-response factor that reflectes tree quality is needed for a proper diagnosis. The purpose of this study was to determine the relationship between nutrient balance and indices of tree quality and to evaluate how nutrient balance and tree quality can be manipulated by fertilizer inputs based on the Diagnosis and Recommendation Integrated System.

In 1984 a factorial N, P, pH, fertilizer source, and fertilizer frequency trial was installed in northwestern North Carolina. A randomized complete block design with factorial combinations of all five factors was used. After three years, the fertilizer trial was analyzed to study the effects of fertilizer additions on foliar nutrient balance and tree quality. Several tree response factors were measured in the fall after dormancy. Statistical methods such as correlations and multivariate discriminant analysis were used to determine which response factors were correlated with foliar nutrients and which factor most governed tree quality. DRIS indices were calculated for six independent plots of different fertility treatments.

Basal diameter (BD) was the strongest discriminator of tree quality and was used as a substitute for yield in the DRIS analyses. The importance of nutrient intensity was demonstrated since significant nutrient / dry matter ratios were calculated for N, P, K, and Mg. Balance was shown to be important since the indices for N, K, and Mg were a function of the four other nutrient

ratios other than dry matter, and the P and Ca indices were a function of three nutrient ratios other than dry matter. Nutrient balance was also shown to be important by the significant relationship of BD as a function of the nutrient balance index (NBI). When NBI had a relatively small value, large BD trees were produced; as NBI values increased, BD decreased. Fertilizer additions that created nutrient imbalances also decreased BD, in spite of the high nutrient intensities found in the foliage. These results show that nutrient balance in Fraser fir foliage, as well as nutrient intensity, is important for producing optimal Christmas tree quality.

Acknowledgements

This project, as usual, is the whole of many parts. Without the assistance of the following people, the parts would still be parts.

First, I would like to thank my chairman Dr. James A. Burger who supplied the glue to stick the whole thing together. My committee members Drs. John R. Seiler, David W. Smith and Thomas J. Nichols deserve my thanks for their patience and sticking with me to the very end.

Numerous people helped out by collecting and analyzing each and every piece of data. A few special friends include , , , and (along with her work study students) who all worked through thick (rain, sleet, fog, wind, snow, and BS) and thin (jackets and patience), but we put it all together anyway. I cannot forget the assistance of my "devil-advocates" and . I would also like to thank who *"scripted"* me to death, but I returned the favor. Finally, I would like to acklowledge all the "Burger Boys" past and present, their advice and frendship will never be forgotten.

Last but not least I would like to thank the most important people in my life, my family. My parents allowed me to "do what I had to do." My brothers , , , and (and their wives and children) always gave me their love, friendship and courage, and even though we are miles apart, we will always stick together like birds of a feather. It is to my family, however large is grows, that I dedicate this thesis.

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Introduction

Fraser fir [*Abies fraseri* (Pursh) Poir] is extensively planted for Christmas tree production in North Carolina and southwestern Virginia. In 1986, the National Christmas Tree Association reported that North Carolina and Virginia harvested 1.9 and 0.9 million Christmas trees, respectively, of which 55% were Fraser fir in North Carolina and 26% were Fraser fir in Virginia. Production of this species is expected to double in these states in the next two years. Compared to other popular Christmas tree species, such as white pine (*Pinus strobus* L.), Fraser fir has a higher value. In 1986, white pine brought an average of $9/tree wholesale, while Fraser fir averaged $21/tree (Nichols 1988). Despite its economic importance, however, very little research has been published relative to its responsiveness to fertilization.

Responses to fertilization include: increased height growth, shorter rotation length, greater needle length and retention, improved foliage color, and better bud development. Many Christmas tree species respond favorably to fertilization. These species include white, Virginia (*Pinus virginia* Mill), and Scotch (*Pinus sylvestris* L.) pine; Douglas-fir [*Pseudotsuga menziesii var. menziesii* (Mirb.) Franco]; white [*Picea glauca* (Moench) Voss] and Colorado blue (*Picea pungens* Engelm.) spruce; and Fraser fir's close relative, balsam fir [*Abies balsamea* (L.) Mill.] (Brown 1974). However, the factors limiting growth need to be adequately diagnosed before any fertilization program can be initiated.

Nutrition is related to important Christmas tree quality characteristics. For balsam fir the number of buds is related to foliar phosphorus content (Timmer et al. 1977); needle color, length, and retention are related to foliar nitrogen, calcium, and magnesium content (Timmer et al. 1977, Jablanczy 1971). Height and diameter are expressions of all nutritional, environmental, and genetic factors that affect the tree, such as soil fertility and moisture, sunlight, competition, and seed source.

A diagnostic system that relates responses of tree quality characteristics to nutritional status as measured by foliar nutrient levels would be a useful tool for prescribing fertilizers. Although tree grade seems to be an ideal measure of quality, in that it is an expression of overall tree appearance, measuring a growth factor, such as basal diameter, would be more objective. Even an expert grader cannot estimate a tree's nutritional status by making a judgment from its overall appearance. One or several tree response factors, such as diameter or leader length, if correlated with foliar nutrient content, would provide an unbiased estimate of nutritional status and tree response.

The Diagnosis and Recommendation Integrated System (DRIS) has proven useful in quantifying plant-limiting factors and has been used to improve quality and yield in agricultural and tree plantations (Beaufils 1973, Leech and Kim 1981, Truman and Lambert 1981). DRIS involves measuring specific plant quality or yield factors and relating these factors to plant nutrient content. DRIS was developed by E.R. Beaufils (1957) who successfully improved quality and yield of latex from rubber tree (*Heavea brasiliensis* Muhl. Arg.) plantations in Vietnam. Other applications include improving sugarcane (*Saccarum officinarum* L.) yields in Hawaii and Florida (Elwali and Gascho 1983 and 1984, Jones and Bowen 1981), and corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and soybean (*Glycine max* L.) yields in South Africa and the United States (Beaufils 1971, Escano et al. 1981a and 1981b, Amundson and Koehler 1987; Sumner 1977a, 1977b, 1977c, 1977d, and 1981).

DRIS uses nutrient ratios (%N/%P, %P/%N, %K/%P, etc) of a high-yielding or high-quality population to establish standard indices called norms. The reference population would consist of high-quality Christmas trees with optimal nutrient content. Candidate plantations have their nutrient ratios compared to those of the reference population. Deviation of the ratios of the candidate plantations from the standard norms indicate nutrient deficiencies and imbalances. DRIS is capable of diagnosing multiple nutrient deficiencies and ranking the nutrients in order of requirement. Factorial fertilizer trials are then used to calibrate diagnostic indices which enable a specific fertilizer recommendation to be associated with a specific diagnostic index.

Preliminary work has been done on the use of the DRIS method for developing a nutrient diagnostic and fertilizer recommendation program for Fraser fir Christmas trees (Hockman 1986). Based on foliar analysis collected from a Fraser fir Christmas tree plantation, preliminary DRIS diagnostic norms have been calculated for the species. However, these norms were based on grade rather than morphological tree response factors.

The objectives of this research are to: 1) investigate measures of tree quality such as diameter, number of buds, and leader length, that might be used as a surrogate for yield in the DRIS program; 2) establish a reference population based on the yield surrogate; and 3) investigate the relationship between fertilizer inputs, nutrient balance, and tree quality factors. Results of these studies should lay the foundation for developing a fertilizer recommendation program for producing high-quality Fraser fir Christmas trees.

Literature Review

Fraser Fir Christmas Trees

The Fraser fir Christmas tree industry is a thriving enterprise. The North Carolina economy nets 30 million dollars annually from the sale of Fraser fir Christmas trees, wreaths, and roping (Anonymous 1987a, Sorrels 1986). The sale of North Carolina's Fraser fir alone accounts for almost 10% of the total national Christmas tree market. While the sale of other Christmas tree species is declining, Fraser fir growers hope to increase their share of the market to 20% (Anonymous 1987a). In 1986 and 1987 Fraser fir has been awarded the National Grand Champion Prize by the National Christmas Tree Association. This award enabled the growers to supply Fraser fir to the White House as the National Christmas tree which further helped to increase the popularity of this species on a nationwide basis.

Much effort and expense is involved in producing high-quality Fraser fir Christmas trees. Cultural techniques such as fertilization, weed and pest control, and shearing means that each tree may be touched by the grower more than 130 times from planting to harvest, eight years later (Anonymous 1987b). Recently, many cultural practices used in producing Fraser fir Christmas trees have been extensively studied. Vegetative propagation, cold storage, dormancy, germination, establishment and growth, herbicide use, shearing practices, insect and disease control, and marketing are among the treatises published (Adkins et al. 1984, Blazich and Hinesley 1982, Brown 1979, Bruck et al. 1984, Gardner 1978, Hinesley 1981, 1982a, and 1982b, Hinesley and Blazich 1980 and 1981, Hinesley and Salveit 1980, Jones 1979, Merril et al. 1981, Pound 1981, Swan and Swan 1979a and 1979b, Vodak and Leuschner 1985, Weatherspoon and Hinesley 1980, Whitfield 1982, Wicker 1979). But few research articles are published on Christmas tree fertilization, and fewer yet on Fraser fir Christmas tree production. Although the North Carolina State University Extension Laboratory makes fertilizer recommendations for Fraser fir growers, these are based on soil analyses. However, soil analyses are not always reliable. For example, Bruns (1973) found no correlation between soil and foliar nitrogen (N) content in balsam fir Christmas trees (Table 1). He then compared the foliar N content between dark and light colored trees. In every case the light colored trees had lower N contents (Table 1). On a relative basis the light green trees were N deficient. Some benefits of tissue analysis are demonstrated. The foliar nutrient status of N could be diagnosed on a relative or site specific basis, while soil analysis could not make such a diagnosis. On a relative basis, a reference population (dark trees) and a candidate population (light trees) could be established without pre-established soil or foliar critical levels. However, on a site specific basis, location 1 produced trees with the highest foliar N on a site that contained the lowest amount of soil N, while trees with the lowest foliar N values were produced on location 2, which had soils that contained the highest amount of N. Hence, soil analysis could not make a meaningful diagnosis. A method is needed that can quantify relative deficiencies and prescribe corrective treatments, based on foliar analysis.

Table 1. Mean soil and foliar N on three balsam fir Christmas tree plantations (Bruns 1973).

Location	Soil	Foliage[1]	Dark Trees	Light Trees
	-#/Ac-	%		
1	5440	1.81	1.93	1.69
2	7440	1.53	1.57	1.49
3	6240	1.41	1.65	1.18

1. Average over the plantation, significance of means was not reported.

Christmas Tree Fertilization

The use of fertilizers in Christmas tree production has prompted some investigation of its benefits. The following examples represent the scope of Christmas tree fertilization research in the past two decades.

Thor (1965) and White (1966), both demonstrated that placing fertilizers directly in the planting hole decreased seedling survival of spruces and firs. They suggested banding as an alternative method of placing fertilizers at time of planting, acknowledging that, with this method, weed control is necessary. According to Thor (1965) phosphorus (P) alone, promoted height growth of white pine and Fraser fir for 2 - 3 years. White (1966), and Richards and Leaf (1971) advised using a complete N, P, and potassium (K) fertilizer for preventing nutrient deficiencies unless a diagnosis confirms a specific deficiency; this was a general prescription for all Christmas tree species. White (1966) also stated that micronutrient deficiencies are rare in Christmas tree species in general. Douglass (1966) suggested that as Christmas trees age, fertilizer applications should be increased. Richards and Leaf (1971) described three stages in Christmas tree development: establishment, growth, and finishing. Each of these stages may require different fertilizer prescriptions to accomplish desired growth and quality development.

Several authors have published research articles on the physiology, efficiency (effectiveness), and advantages of fertilizing Christmas trees. Hu and Burns (1979 and 1980) studied the advantages of fertilizing a Virginia pine Christmas tree plantation in Louisiana. On half of the plantation 8-8-8 fertilizer was applied at time of planting and once in the spring every year thereafter. The fertilized trees had better color development after two years. After four years, the trees were harvested and the fertilized trees were fuller and "more attractive," thus, many more of them were sold. Turner (1966 and 1973), working with Christmas trees in Washington, found that N improved foliar color on a 15-yr-old natural stand; shearing did not affect foliar nutrient levels; and fertilized trees did not express seasonal color changes. The best fertilizer treatments were N, N-P-K, and N-P-K-sulfur

(S)-magnesium (Mg). Nitrogen alone significantly increased leader length, but P or K did not. However, too much N over stimulated leader length, which created a sparse appearance.

More extensive studies have been done on balsam fir. Jablanczy (1971) determined that lime improved needle color and retention in plantations located in the Canadian Maritime providences. However, Timmer and Stone (1978), and Czapowskyj et al. (1980) saw no balsam fir response to lime in their studies in the same region of Canada, and in Maine, respectively. Timmer and Stone (1978) recorded increased needle and leader length, lateral branch growth, and foliage color with N, N-P, N-K, and N-P-K fertilizer treatments. Significant increases in bud density and development were also attributed to P applications. On the other hand, too much N may cause problems with fall hardening and frost damage in balsam fir (McKell 1980). The most complete study on fertilizing balsam fir was conducted and published by Bruns (1973). In plantations located in New Hampshire, he tested the results of various fertilizer treatments on Christmas tree growth and development. Applied nutrient elements included N, P, K, Calcium (Ca), Mg, S, and a complete N-P-K fertilizer. Leader length, bud and branch density, and needle color were evaluated. N alone and N-P-K produced significant increases in leader length over a 2-year period. The complete N-P-K treatment had no effect on bud density and elongation, however, bud formation was significantly increased (i.e., as leader length increased, more buds formed, but the number of buds per unit length of leader remained constant). Needle color was improved by the complete treatment, a result which lasted two growing seasons. The author also tried foliar analysis between dark and light trees to diagnose nutrient deficiencies, but other than the darker trees containing more N, results were not significant.

Only two studies were found describing the effects of fertilizer treatments on Fraser fir Christmas tree growth. Thor (1965) studied the effect of fertilizer treatments on Fraser fir at time of planting. As noted earlier, placing fertilizer in the planting hole greatly reduced survival, especially when the fertilizers contained N. Phosphorus (which was also placed in the planting hole) was the only treatment that did not kill the Fraser fir seedlings. Thor recommended avoiding nitrogen fertilizers at time of planting, and that P be added only if the soils test low in phosphate. However, the poor survival was more likely due to excessive N fertilization rather than the placement of the N fertilizer in the planting hole. Douglass (1966) used factorial combinations of N, P, and K at rates of 0.0, 7.0, and 14.0 g/tree to study the effects of fertilization on height growth of Fraser fir in North Carolina. After four years, the N-K treatment at rates of 7.0 g/tree per nutrient produced the best height growth. Phosphorus retarded growth despite a soil analysis that suggested low soil P availability. In neither case was fertilizer effect on tree quality studied.

These examples demonstrate the lack of a reliable diagnostic and prescriptive method to promote efficient and effective fertilization for producing high-quality Christmas trees. Additional problems in developing a fertilizer program for Christmas trees are: the localization of the industry, the small size of the industry in comparison to other tree based industries (Brown 1974), the lack of scientific and statistical designs in studying responses to treatments (Timmer et al. 1977), and lack of an objective or quantitative measure of response to added nutrients. As a consequence, fertilization has been done with little knowledge of the type, amount, and timing of fertilizer actually needed (Brown 1974).

Initiating a Fraser Fir Christmas Tree Fertilizer Program Using DRIS

There are five important points in developing a fertilization program for any particular set of circumstances (Richards and Leaf 1971):

1. Understanding nutrient availability and tree nutrition needs;
2. Assessing the nutritional status and needs of the trees;
3. Determining kinds and rates of fertilizers to use;
4. Timing the fertilizer applications within a season and over the tree rotation;
5. Correcting soil pH for improved nutrition.

Once there is an understanding of the first two points, the last three can be determined using a factorial fertilizer trial, applied throughout the range of the crop to be studied. Nutrient availability is normally assessed through soil analysis. Determining tree nutritional status and demand is more difficult using soil analysis for a nutrient diagnosis. However, a nutrient diagnosis can be made by comparing the foliar nutrient status of high-quality trees to that of low-quality trees.

Tissue analysis is the most beneficial and practical method for obtaining information about the nutritional status of a tree. Foliage nutrient content represents a measure of all the plant, soil, and environmental factors which have influenced nutrient accumulation by the tree. If soil nutrients are not offered in optimal intensity and balance, then needle analysis will expose deficiencies and imbalances in nutrient concentration. Tissue analysis determines the direction and extent of nutrient imbalance within a plant (Shear et al. 1943). Before such a diagnosis can be made the optimal foliar nutrient contents of a species needs to be known.

Although the critical concentration method is employed most often in determining plant nutrient content, significant evidence exists that nutrient ratios better express plant nutritional status (Shear et al. 1943, Beaufils 1973, van den Driessche 1974, Sumner 1978 and 1979). The critical level approach has many weaknesses, the most serious of which is its lack of consideration of more than one factor at a time. This weakness results because optimal levels depend on an interaction of all nutrients. The Diagnosis and Recommendation Integrated System (DRIS), described below, uses nutrient ratios to access the levels of all nutrients simultaneously (Jones and Bowen 1981).

Reference populations of high-quality trees establish the standards to which all other trees or plantations are compared (Beaufils 1973). The nutritional status of reference trees, whether as critical concentrations or nutrient ratios, represent the ideal nutritional status. DRIS calculates standard norms, from nutrient ratios of a reference population, consisting of high-quality Fraser fir Christmas trees. Diagnostic indices, derived from nutrient ratios of candidate populations, are determined and compared to the reference population norms for a nutrient assessment.

By comparing the nutritional status of candidate plantations to the reference standards, a diagnosis of the candidate trees is possible. Then, using factorial fertilizer trials, recommendations for corrective fertilization can be developed by associating a given index level with a positive tree response to certain combinations and rates of added nutrients. In this way, differences between the standard and candidate population indices are calibrated to specific fertilizer applications. The result is a diagnostic and recommendation procedure which establishes an efficient fertilizer prescription program.

Preliminary DRIS norms have been established for Fraser fir Christmas trees based on foliar analysis (Hockman, 1986). These norms were established using Christmas tree grade, a subjective measure of quality, as a surrogate for yield in the DRIS function equations. However, since the goal of DRIS is to diagnose nutrient deficiencies, an objective, nutrient-sensitive growth response factor should be used as the surrogate for yield. The response factor should show that quality can be used in place of yield if a factor describing quality can be quantified; then a relationship between growth response, quality, and nutritional status can be established.

Diagnosis and Recommendation Integrated System (DRIS)

The Diagnosis and Recommendation Integrated System (DRIS) developed by Beaufils (1973) uses nutrient ratios to define the status of nutrient intensity and balance in plants. This method is a form of plant, soil, and environmental calibration which takes into account as many factors affecting yield or quality as are capable of quantitative or qualitative expression (Beaufils 1973, Sumner 1974). External (soil and environmental) characteristics and internal (plant) characteristics are related to yield (Beaufils 1973). Examples of soil characteristics may include nutrient and moisture contents, organic matter, bulk density, and porosity. Environmental characteristics may include climate, rainfall, date of planting, and amount of fertilizer or lime applied. Plant characteristics may involve genetics and seed source, expressions of tissue composition, moisture contents, growth measurements such as diameter and height, and morphological characteristics such as needle length and color, leader length, number of buds, and bud density. These factors are quantified and used to develop diagnostic indices which are calibrated to yield or quality. The DRIS method establishes standard indices, called norms, which are used for diagnosing deficiencies or excesses of these factors and recommending corrective treatments for obtaining a high probability of increasing yield or quality (Beaufils 1973).

There are two general principles basic to understanding the interpretations of the DRIS indices (Beaufils 1973). First, whenever the value of a nutrient factor is either too low or too high, yield is directly limited; whenever the nutrient content falls within the limits corresponding to the highest yield class, yield can still be very low because another nutrient or growth-regulating factor is limiting. Figure 1-a,b,c (Walworth et al. 1986), shows how a nutrient at an optimal level, in this case N, P, or K, may still not produce optimal yields because another growth factor (not necessarily another nutrient) is limiting yield. Second, the diagnosis classifies nutrients in increasing order from most limiting to least limiting. Both the relative order and degree of limitation is diagnosed. Therefore, both balance and intensity is automatically incorporated into the diagnosis (Sumner 1977d, 1977e, and 1979). The magnitude of a DRIS-derived index is an indication of the relative degree of the deficiency or excess. Balance is established since the sum of the indices always equals zero while each index will deviate either negatively or positively from zero depending on whether the nutrient is relatively deficient or excessive, respectively (Sumner 1977c, 1977d, and 1977e, Sumner et al. 1983). The indices do not indicate absolute deficiency or excess; they are a relative ranking of the nutrients in order of demand by the plant (Kelling et al. 1981).

The range of the indices, called nutrient balance index (NBI), calculated by summing indices irrespective of sign, indicates how far the plant is from nutritional balance (Sumner 1978). A large value indicates the plant is very unbalanced from a nutritional standpoint, while a small value indicates a relatively balanced plant in terms of nutrition (Beaufils 1973, Erickson et al. 1982, Elwali and Gascho 1984). Large yields can result only when NBI is small, although low yields may still occur if other nutrients or growth-regulating factors are limiting, but not included in the analysis (Walworth and Sumner 1987).

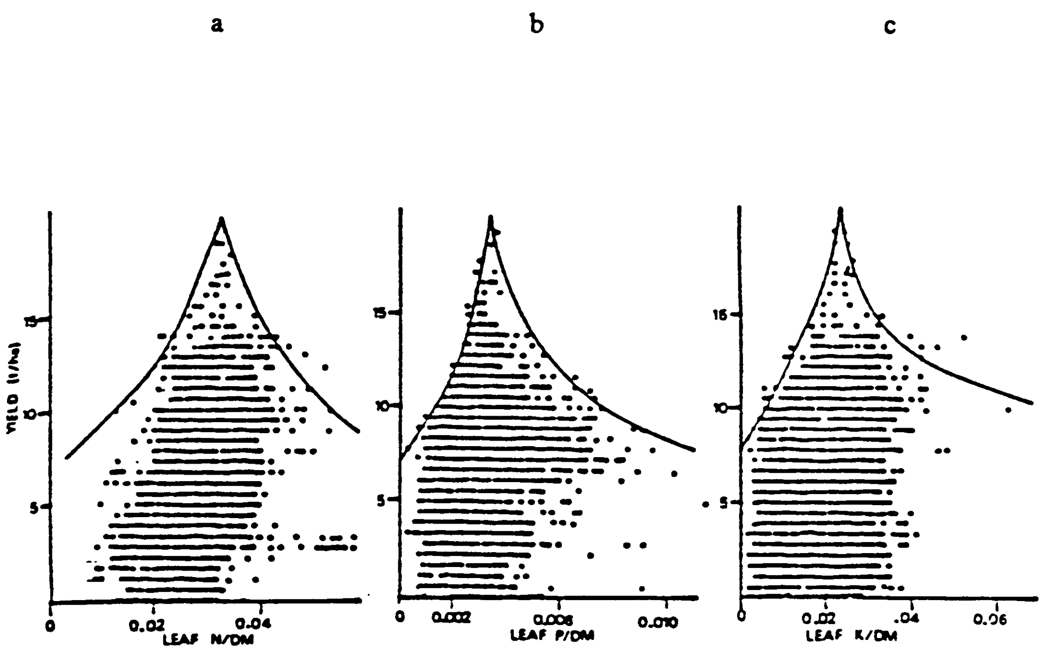

Figure 1. Relationship between corn yield and foliage nutrient concentrations of N, P, and K (Walworth et at., 1986).

To develop DRIS for a given plant species the following requirements must be satisfied whenever possible (Beaufils 1973):

1. All factors suspected of having a possible effect on plant yield or quality must be defined;
2. The relationship between these factors and yield or quality must be described;
3. Calibrated norms or reference data must be established;
4. For each new set of environmental conditions, the norms or reference data must be continuously refined.

All plant, soil, and environmental factors combined could limit quality and yield. The relationships between these factors must be established since they ultimately control DRIS diagnoses. To make diagnoses, candidate indices from low-quality trees are compared to reference norms from high-quality trees. The population of healthy and vigorous trees must be continuously expanded to account for all levels of factors that produce reference quality trees. Thus the norms undergo constant refinement and testing in order to establish a unique reference population.

Since nutrient levels in plant tissue are a measure of the influence of all plant growth-regulating factors, and DRIS foliar analysis is more fully developed than soil or environmental analysis (Elwali and Gascho 1984), tissue analysis is the logical beginning in establishing diagnostic DRIS norms for Fraser fir Christmas trees.

To formulate DRIS foliar nutrient norms, samples of a population are collected on the species of interest. Two subgroups are identified based on yield or quality, i.e. a high-yield population verses a low-yield population. Since DRIS was initially developed using rubber trees, and intensively investigated with corn and sugarcane plants, criteria for separating high- and low- quality subgroups of Fraser fir are poorly developed. Quality measures and values exist for sugar and latex. However, no procedures exist for choosing the most diagnostic growth response factor for nutritional assessment in trees, or for choosing the critical level between high- and low- quality populations based on tree-response factors such as height or diameter.

After separating foliage sample values into high and low subgroups based on yield or quality, each element in the analysis is expressed as ratios of each other, i.e. %N&/dry matter (DM), %N/%P, %P/%N, %N×%P, etc. A Kolomogorov-Smirinov test is applied to each subgroup to check for normality, at least for the high-quality population. Then the mean, standard deviation, coefficient of variation, and variance for each form of expression is calculated. Expressions having nonsignificant mean separations (μ good = μ low) and significant variance differences (σ^2 good < σ^2 low) between the two subgroups, are retained as being discriminatory (Meldal-Johnsen and Sumner 1980). These discriminatory expressions are substituted into the appropriate equations (Beaufils 1973) which produce ratio functions (Equations 1 and 2). The ratio functions are linked together to produce diagnostic norms (Equations 3 - 7).

$$f(A/B) = (100\times[(A/B)/(a/b)] - 1)(k/CV) \qquad [1]$$

if a/b < A/B

$$f(A/B) = 100\times[1 - (a/b)/(A/B)](k/CV) \qquad [2]$$

if a/b > A/B

$$Nindex = \frac{(fN/P + fN/K + fN/Ca + fN/Mg)}{4} \qquad [3]$$

$$Pindex = \frac{(fP/K - fN/P - fCa/P - fMg/P)}{4} \qquad [4]$$

$$Kindex = -\frac{(fN/K + fP/K + fCa/K + fMg/K)}{4} \qquad [5]$$

$$Caindex = \frac{(fCa/P + fCa/K - fN/Ca - fMg/Ca)}{4} \qquad [6]$$

$$Mgindex = \frac{(fMg/N + fMg/P + fMg/K + fMg/Ca)}{4} \qquad [7]$$

Where A/B is the ratio of nutrient *A* to nutrient *B* of the good population and a/b is the ratio of nutrient *A* to nutrient *B* of the low population, CV is the coefficient of variation for the good population, and k is a constant that regulates the magnitude of the indices, and can be set at a convenient level.

Through this linking procedure both intensity and balance among all nutrients is diagnosed. The optimal index or norm is set at zero, while deficiencies have negative indices and excesses have positive indices. The magnitude of the indices denotes the seriousness of the imbalance and establishes the order of limiting factors. Once the norms are established, they must be validated before they can be used for diagnosis and recommendation.

In order to test the efficacy of diagnostic indices, they need to be used to make diagnoses in which responses to known fertilizer treatments have been recorded. Factorial experiments in which yield or quality responses have been obtained are used to evaluate the norms (Meldal-Johnsen and Sumner 1980). If an increase in yield is obtained when a nutrient that has been designated as most limiting is added, then the diagnostic indices are validated.

Elwali and Gascho (1983) tested foliar norms of sugarcane. Using a split-plot design and factorial fertilizer applications at time of planting, DRIS indices were used to designate nutrient deficiencies for midseason supplemental diagnosis. When a diagnosis was made, half of the plot was fertilized, the other half was not treated. Cane and sugar yields were increased using the DRIS-guided treatments. On coastal bermudagrass (*Cynodon dactylon* sp.) Tarpley et al. (1985) applied the nutrient designated as most limiting according to DRIS foliar diagnosis and tallied the number of responses. For instance, N was diagnosed as being most limiting in 386 plots, when N was applied, 92% of these plots responded. Other analyses with DRIS consistently had responses in at least 80% of the plots. Once these norms are verified, they can be used as standards in a variety of analyses. With the use of factorial field trials, the indices may be calibrated to fertilizer recommendations which will correct nutrient imbalances. If nutrition is most limiting yield, consideration of a greater number of nutrients in the diagnosis improves confidence of finding the most limiting nutrients (Beaufils 1973, Walworth and Sumner 1987).

Diagnostic norms should be tested for their ability to make meaningful diagnoses which have a high probability of increasing yield (Sumner 1977c, 1977d, and 1979, Kelling et al. 1983). The norms should be able to predict yield responses that were in fact obtained in the experiment. The test is carried out by selecting a particular treatment in the experiment, making a diagnosis of the situation and then selecting another treatment in which the particular element found wanting was applied to establish whether or not a correct diagnosis was made. A correct diagnosis would be indicated when a positive yield response was obtained to the particular treatment (Sumner et al. 1983).

For example, Kelling et al. (1981) applied fertilizer treatments to alfalfa (*Medicago sativa* L.) according to DRIS recommendations (Table 2). As K and P treatments were progressively

Table 2. Effect of fertilizer treatments on nutrient composition and DRIS indices of alfalfa (Kelling et al. 1981).

Treatment			Nutrient Composition				DRIS Indices				
P	K	S	N	P	K	S	N	P	K	S	NBI
			%								
0	0	0	2.99	0.24	0.84	0.26	34	9	-81	38	162
0	1	0	3.14	0.24	1.46	0.25	19	-7	-30	18	74
0	2	0	3.21	0.25	1.55	0.29	16	-7	-30	21	74
0	3	0	3.14	0.24	2.05	0.25	12	-14	-8	10	44
1	3	0	3.10	0.25	2.13	0.24	10	-12	-6	8	36
2	3	0	3.33	0.25	1.95	0.25	15	-13	-13	11	52
2	4	0	3.15	0.26	2.60	0.24	6	15	-5	4	30

increased, NBI decreased as yield and nutrient composition for those nutrients increased. After the 2-3-0 P-K-S treatment, yield declined, although NBI was low, indicating another factor (not necessarily another nutrient) was limiting yield.

Once the DRIS norms have been established, they must be continuously refined to further define the optimal population under more variable conditions. Nutrient ratios of high-yielding populations of a species are not significantly different regardless of the soil on which the species is grown (Tarpley et al. 1985). DRIS norms represent "optimal" plant composition, and optimal or high-yielding plants under any set of environmental conditions should be similarly composed (Beverly et al. 1986). Samples of a population of the species under investigation should be studied on a spectrum of site conditions. Foliar nutrient analyses of the samples can be included in the refinement of the population norms used as standards. When applying the DRIS method, indices of a population requiring diagnosis are compared to the norms of the standard population, so the standard norms must be reliable under any set of environmental conditions that the species may experience (Beverly et al. 1986). However a recalibration of the indices is needed for each environmental condition, since a different fertilizer prescription will be needed to correct the deficiencies.

Conclusion

DRIS can diagnose for plant, soil, and environmental factors that limit growth and yield. The strength of this method lies in its ability to diagnose multiple nutrient deficiencies, and to rank the nutrients in order of need. Through factorial fertilizer trials, DRIS indices can be calibrated to corrective treatments, however, the norms must be subjected to rigorous testing. To test the efficacy of diagnostic norms, they should be used to make diagnoses on factorial fertilizer trials where responses to yield or quality are known. The norms must be continuously refined to be reliable under all circumstances. Although the diagnostic methods are well developed, no procedure exists for choosing the appropriate growth or quality factor reflecting nutritional status, and locating the critical value between high- and low- quality populations for Fraser fir and many other crops to which the method might be applied.

Materials and Methods

Fertilizer Trial

The study site was located on Bald Mountain (elev. 1340 m) in Watauga county, North Carolina (lat. 36°21′N, long. 81°39′W). The Fraser fir plantations were established on natural grassy balds where soil characteristics were highly variable due to extremes in topography. Slope, aspect, and landform influenced the development of soil physical characteristics.

Two soil series were represented, Ashe (coarse-loamy, mixed, mesic, Typic Dystrochrept) and Watauga (fine-loamy, mixed, mesic Typic Hapludult). These residual soils formed from weathered mica shist, mica gneiss, and granite. Large outcrops of bedrock were common in the landscape and many coarse fragments were found on the soil surface and in the profile. These soils had thick A horizons (+ 20 cm), with high organic matter content (8-12 %), and strong acidity (3.5-5.5). The inherent fertility was moderate to high (Hockman 1986).

The climate was typical of the Blue Ridge physiographic province with the mountains moderating temperature and rainfall. There are about 140 frost free days for the growing season with an average precipitation of 130 cm annually. The average normal daily January and June temperatures are 1 and 20°C, respectively (Hockman 1986).

The Fraser fir Christmas tree fertilizer trial was established in 1984 with 3/2 seedling stock raised in the plantation liner beds. A randomized complete block design with factorial treatments was used. The trial consisted of three factorial studies which allowed the relationship between the effects of fertilizer inputs on tree nutritional balance to be investigated.

Study number one was a three-way factorial (2×3×3) that included frequency of fertilization at two levels; annual spring applications beginning at time of planting (F1), and at time of planting followed by fertilization every third year (F2); nitrogen (N) was applied at three levels, 0, 43, and 86 kg N/ha, and phosphorus (P) was applied at three levels, 0, 67, and 134 kg P/ha. Fast release sources of fertilizer (S1) as explained below were used for this study.

Study number two was also a three-way factorial, with N and P being two factors while source was studied in place of fertilizer application for the third factor. Two types of sources were used; fast release (S1) which included NH_4NO_3 for N, and triple superphosphate (TSP) for P, and slow release (S2) which included Osmocote (37-0-0) for N, and ground rock phosphate (GRP) for P. The N and P rates were the same as in study one. F2 was used for this study. Study one and two were partially superimposed since two of the three factors (N and P) were shared (See appendix A-1, 2, 3).

Study number three was a two-way factorial (3 × 3) with frequency of fertilization and pH. Two frequencies described in study one were used with the third frequency of fertilization defined as no fertilizer applied until the spring of the third growing season and then every year thereafter. The three soil pH treatments included lowering pH to 4.5, raising pH to 6.5, and no pH treatment with native pH being 5.5. Elemental sulfur was used to lower soil pH at a rate of 864 kg/ha. Dolomitic limestone (CCE 100%) was used to raise soil pH at a rate of 8037 kg/ha for replication one while 9823 kg/ha was used for replications two and three. The lime rates were established by an SMP soil pH test performed by Hockman (1986). This trial was fertilized with 324 kg NPK/ha (17-17-17) annually in the spring and 437 kg DAP/ha annually in the fall.

Each of the treatment combinations were replicated at each of three sites (blocks). Plots were numbered 1-36. Treatments were assigned randomly to each plot in each replication (Appendix A-1, 2, 3). Each plot contained 30 trees on a 1.4 × 1.9 m spacing. Plot layout was such that each plot had five rows (5 trees per row) and six columns (6 trees per column). The first and fifth rows, and the first and sixth columns were used as a buffer. This left nine trees at the plot center as the measurement trees, (Appendix B). Fertilizer amounts were calculated on a per tree basis (Appendix C), but was applied on a per row basis. Calibration took place in the laboratory where plastic cups were filled to the required amount on a Mettler Delta Range PC 4000 balance. Each cup was labelled with the fertilizer type, amount, and appropriate plots. Since the objective was to fertilize the whole rooting zone, fertilizer was banded throughout the rows. The fertilizer was hand applied within a band which was 1.10 m wide with the trees at the center (0.55 m from each side of the band). All cultural treatments except fertilization was conducted operationally by the plantation managers.

Field Procedures

Sampling was done during fall dormancy after the third growing season. All morphological characteristics that were presumed related to tree quality were measured in the field. Measurement and sampling were done according to the sampling window and standards that Hockman (1986) established. For each of the nine sample trees per treatment combination the following data were collected: basal diameter (cm), current year (1986) needle length (mm) measured from needles taken off 1984 and 1985 primordial branches on the south side of tree, needle color, current year terminal leader length (cm), proximal distance to first lateral bud on the terminal (mm), number of lateral and whorl buds on the leader, length of terminal bud (mm), length of previous year (1985) terminal leader (cm), number of buds on previous year terminal leader, number of buds on previous year terminal that elongated in the 1986 growing season, tree quality index, and corresponding soil samples from each of nine sample trees.

Basal diameter and length of terminal bud were measured with calipers. Measurements of length and distance were made with a metric scale. Current year needle color was determined with the Munsell foliage color charts. Leader lengths were measured from the previous-year whorl scar to the current-year whorl scar. Tree quality index was determined using the U.S. Standards for Grades of Christmas Trees (USDA 1973) as a guide. A datamyte 1000 data collector (DataMyte Corp.) was used to collect field information. The field data were transferred to a floppy disk in a portable IBMpc for temporary storage at the study site. Branches collected from the trees for needle length and color determinations were put into plastic bags and kept on ice in the field and refrigerated (4°C) upon returning to the laboratory. Needle length and color were determined immediately after returning to the laboratory; the process took about a week to accomplish.

Laboratory Procedures

Following needle color and length measurements, the foliage was stripped from the branches, dried, and ground in a Wiley mill to pass a 1 mm sieve. The ground tissue samples were stored in coin envelopes under refrigeration (4°C) until nutrient analyses were performed. Prior to laboratory analysis, the foliage was dried to a constant weight at 65°C.

Foliar samples were analyzed for percent N, P, K, Ca, and Mg. Nitrogen was determined using Total Kjeldahl Nitrogen (TKN) digestion procedures (Bremner, 1965), and ammonia-salicylate colorimetric techniques on a Techicon autoanalyzerII. Total P was determined using Murphy-Riley (1962) procedures on extracts of dry-ashed foliage samples. The dilute double-acid (0.5M HCL and 0.25M H_2SO_4) method (Olsen and Dean 1965) was used to extract K, Ca, and Mg from the dry-ashed samples. Determinations were made on the Perkin-Elmer 460 atomic absorption spectrophotometer, absorption for Ca and Mg, and flame emission for K. National Bureau of Standards pine tissue was used as a calibrant for all nutrients analyzed (NBS 1979).

Field data were transferred from the floppy disk to the mainframe computer for analysis. The SAS statistical analysis system (SAS institute Inc. 1985) was used for all data handling. Pearson correlation coefficients were used to correlate tree quality index (TQ), nutrient factors, and measures of quality (e.g. basal diameter, height, etc). Quality factors that were significantly correlated with TQ and nutrient contents were subjected to multivariate discriminant analysis procedures to determine which factor most governs quality (TQ). This quality factor was used as a surrogate for yield in the DRIS analysis. The cut-off point for subdividing the population into high- and low-quality subgroups, was established using F-tests on candidate subgroup nutrient ratio variances formed from a spectrum of percentiles. The subgroup that had the most number of significant ratios for the high-quality population had its lowest value labelled as the critical diameter. DRIS indices were calculated according to established procedures (Beaufils 1973, Erickson et al. 1982, Elwali and Gascho 1984, and Walworth and Sumner 1987), with some modifications (Jones 1981, Needham 1986).

Applying DRIS To Fraser Fir Christmas Trees

Introduction

The Fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas tree industry is highly competitive; growers must produce healthy, vigorous trees in order to survive in the business. Fraser fir appears to respond to fertilization, but little is known about the biology and economics of the response, and even less is known about diagnostic procedures that might be used to assess the nutrient status of this species. A diagnostic technique that is receiving a lot of attention in agriculture is the Diagnosis and Recommendation Integrated System (DRIS). DRIS is a versatile foliar nutrient diagnostic technique that has been applied to many different crops, and has been particularly useful for diagnosing nutrient deficiencies in perennial crops that are fertilized for several successive years. Since its inception by Beaufils (1957), DRIS has been modified to suit the specific circumstances of each species to which it has been applied. An underlying assumption for its application to any crop is that the variance in yield of high-yielding plants is lower than the variance in yield of low-yielding plants. However, from crop to crop, a definition of yield, and delineating between high and low yields, can be quite different.

Most yield measures are an expression of mass (i.e. kg/ha corn, hay, potatoes, etc.) or volume (i.e. m^3/ha wood) of crop produced. In latex and sugarcane crops surrogates for yield that represent an expression of quality rather than quantity have been successfully used in DRIS analyses (Beaufils 1973, Beaufils and Sumner 1976). These examples of yield definitions demonstrate the versatility of the method which is also manifested in the delineations of high versus low yields. Several authors have studied the effect of changing the delineation between high and low yield on DRIS diagnoses. Escano et al. (1981) found that DRIS norms based on the two highest yielding corn plots per replicate (block) gave more accurate nutrient diagnoses than DRIS norms based on the highest-yielding 15% of the experimental population; he reasoned that the first method reduced the effect of climate and site differences. Tarpley et al. (1985) reported that a critical yield level of 5040 kg/ha of bermudagrass resulted in a good population comprised of only high-yielding observations, while using 90% of maximum yield included some low-yielding observations in the good population.

The use of DRIS in forestry has been similar to its use in agriculture except that a suitable response factor, such as diameter at breast height (Kim and Leech 1986), total height (Truman and Lambert 1981), or volume at a given age (Needham 1986), is used in place of total yield. However, in the case of Christmas tree production, trees are marketed based on quality rather than biomass production. Branch and needle density, color, and vigor are examples of tree response factors that are associated with tree quality. In order to use DRIS as a diagnostic technique for Christmas trees, a suitable surrogate for yield must be identified and then used to delineate high-quality trees from low-quality trees. Accordingly, the objectives of this study were to: 1) identify an appropriate nutrient-sensitive response factor that accurately represents tree quality and could be used as a surrogate for yield, and 2) develop criteria for selecting a reference ("good") population with a foliar nutrient balance that represents the highest quality trees.

Materials and Methods

The study site was located on Bald Mountain (elev. 1340 m) in Watauga county, North Carolina (lat. 36°21'N, long. 81°39'W). In 1984 a factorial fertilizer trial was established in three new plantations to study fertilizer treatment effects on Fraser fir growth and development. Thirty-six different fertilization treatment combinations were applied on these sites to 108 thirty-tree plots. This trial created a plot by plot soil fertility gradient which in turn created a gradient in foliar nutrient concentrations and tree response factors.

Treatments in this fertilizer trial included two rates of N and P, two sources of N and P, a single rate of a balanced N, P, and K fertilizer, addition of lime and sulfur for pH adjustment, and three frequencies of fertilizer additions. Details of this fertilizer trial and long-term objectives are described by Kopp (1988). The trial, in this intermediate stage, was used in this study for the sole purpose of creating a gradient in tree response factors that could be correlated with foliar nutrient content. These plots, having received a variety of treatments, were considered analogous to separately-fertilized plantations in that each plot provided a representation of various fertilizer treatments and associated foliar nutrient intensities and balances. These plots were used as 108 separate experimental units for the purpose of this study.

The fol'owing tree factors, presumed to be important to quality and responsive to fertilization, were measured in the dormant fall season when the plantation was three years old: current and previous year leader length (cm), number of lateral and whorl buds on the leader, bud density (number of buds per unit leader length), current-year basal diameter (mm), needle length and color, proximal distance to first lateral bud (mm), length of terminal bud (mm), number of elongating buds on the previous-year leader, and tree quality index (TQ). The Munsell foliage color charts were used for determining needle color and the manual U.S. Standards for Grades of Christmas Trees (USDA 1973) was used as a basis for determining TQ. Three TQ indices were used, #1, #2, and #3. General qualities that designated a #1 tree were a fresh, clean, healthy appearance with heavy needle density, well shaped branches, and no bare spots. The #2 trees were defined the same, except that one side was damaged or bare. Trees with poor needle color, light needle density, and damage or disease or bare spots on two or more sides were considered #3.

Foliar samples were analyzed for percent nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). Nitrogen was determined using total Kjeldahl nitrogen digestion procedures (Bremner 1965), and ammonia-salicylate colorimetric techniques on an autoanalyzer. Total P was determined using Murphy-Riley (1962) procedures on extracts of dry-ashed foliage samples. The dilute double acid method of Olsen and Dean (1965) was used to extract K, Ca, and Mg from the dry-ashed samples. Determinations were made on an atomic absorption spectrophotometer for K, Ca, and Mg. National Bureau of Standards (NBS 1979) pine needle tissue was used as a calibrant for all elements analyzed.

The SAS statistical analysis system (SAS Institute Inc. 1985) was used for all data handling. Pearson correlation coefficients were used to correlate TQ, nutrient contents, and tree response factors. Tree response factors that were significantly correlated with TQ and nutrient contents were subjected to multivariate discriminant analysis procedures to determine which factor most governed quality. This factor was used as a surrogate for yield and was the basis for dividing the Fraser fir population into high- and low- quality subgroups. The cut-off value for subdividing the population was established by maximizing the number of significant ratios between candidate subgroups. Significant or discriminating ratios were those nutrient ratios that had significantly smaller variances in the high-quality subgroup and non-significant mean differences (Beaufils 1973), or significantly smaller variances in the high-quality subgroup and significantly different means (Needham 1986), or non-significant variance differences and significant mean differences (Jones 1981).

Results and Discussion

Hockman (1986) used Christmas tree grades as a response factor to diagnose nutrient deficiencies in Fraser fir Christmas trees. However, the grading system is normally used for trees of harvestable size (plantations at least eight-years-old for Fraser fir) and was not designed for younger plantations. Although he showed that grade was significantly correlated to tree morphological factors, he did not investigate the relationship between grade and foliar nutrient content. Using the tree quality index developed for the present study, the data in Table 3 show that morphological factors were better correlated with foliar nutrients than TQ, and except for bud density, all morphological factors were also highly correlated with TQ. TQ was not correlated with the foliar nutrients P, K, or Ca. The factors that were highly correlated with four foliar nutrients included leader length (LL), number of buds (NB), bud elongation (BE), and basal diameter (BD). Needle length, number of whorl buds, and needle color, although significantly correlated with TQ, were correlated to fewer than four foliar nutrients. Bud density was not correlated with TQ or with three of the five foliar nutrients analyzed. No morphological factor was correlated with P.

Because TQ is a subjective representation of all tree characteristics, and because it is heavily influenced by shearing, it is poorly correlated to nutrients thought to be most important for Fraser fir Christmas tree development. A fertilizer response factor suitable as a substitute for TQ must be objective, contribute to tree quality, and be significantly correlated with foliar nutrient levels. The four factors that most strongly correlated with TQ and foliar nutrient factors (LL, NB, BE, and BD) were subjected to multivariate discriminant analysis (Hair et al., 1987) to determine which factors or combination of factors accounted for the differences between TQ categories. BD was the strongest discriminator of TQ with a highly significant F-statistic of 259 (Table 4). Using only BD in a classification equation, 72% of the trees were correctly classified into the right TQ (Table 4). Adding more independent variables in addition to BD in the classification equation resulted in a diminished ability to distinguish the correct TQ; this is because BD was such a disproportionately strong discriminator while the other factors were weaker discriminators. This analysis suggested that BD was the most suitable measure of responses to fertilization, and that it could be used as a surrogate for yield in DRIS.

The next step in appling DRIS to Fraser fir Christmas trees was to identify the minimum BD associated with high-quality ("high-yielding") trees. The actual cut-off value that splits the population into "good" and "poor" subgroups is not important (Walworth and Sumner 1987), as

Table 3. Pearson correlation coefficients[1] between TQ, tree morphological factors, and foliar nutrients in Fraser fir trees[2].

	Tree Quality Index (TQ)	Morphological Factors: Current Number of Buds	Current Leader Length	Bud Density	Bud Elong.	Basal Diameter
	TQ	-.52***	-.53***	ns	-.25**	-.36***
Foliar Nutrients						
N	-.16*	.57***	.48***	.19**	.40***	.34***
P	ns	ns	ns	ns	ns	ns
K	ns	.38***	.47***	ns	.36***	.35***
Ca	ns	-.21**	-.37***	.18**	-.23**	-.19***
Mg	-.19**	-.67***	-.72***	ns	-.61***	.40***

	Previous Leader Length	Previous Number of Buds	Needle Length	Number Whorl Buds	First Lateral Bud	Needle Color
TQ	-.46***	-.24**	-.18***	-.36***	-.29***	-.18*
Foliar Nutrients						
N	.39***	.40***	ns	.45***	ns	.17*
P	ns	ns	ns	ns	ns	ns
K	.39***	.35***	.17*	.29***	ns	ns
Ca	-.31***	0.22**	ns	ns	.28***	ns
Mg	-.64***	-.63***	ns	-.51***	.17*	-.18*

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

2. Three-year-old plantations.

Table 4. Multivariate discriminant analysis results on Fraser fir tree quality factors most associated with TQ.

Variable	Partial R2	F Statistic[1]
Basal Diameter (BD)	0.3500	259.00***
Leader Length (LL)	0.0547	27.82***
Number of Buds (NB)	0.0103	4.97***
Bud Elongation (BE)	0.0057	2.73*

Variables In Classification Equation	Correct Percent of Classifications
BD LL BE NB	66
BD LL BE	67
BD LL	69
BD	72

1. F-statistics labeled with *, **, ***, are significant at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively ($\alpha = 0.10$).

long as a set of reliable norms are established (Letzsch and Sumner 1984). DRIS norms for agronomic crops have been developed by dividing populations into "good" and "poor" subgroups based on a generally-accepted level of yield (Letzsch and Sumner 1984). If TQ could be considered an objective quality factor directly responsive to fertilization, then TQ #1 trees in the reference population might be called "good-yielders", and TQ #2 and #3 might be called "poor-yielders." However, because TQ is subjective (which causes it to be dependent on all cultural treatments, including shearing) and is generally not correlated to nutrient content, BD was used as the best objectively-measured discriminator of nutrient status.

To determine a BD cut-off point delineating "good" and "poor" subgroups, the complete experimental population was divided based on BD at the 95, 90, 85, 80, 75, 70, 65, 60, 55, and 50th percentiles, (i.e. at the 95 percentile, 5% of the total population with the largest basal diameters were designated in the "good" subpopulation; the remaining 95% made up the "poor" subpopulation). Although the 95th percentile (an accepted agronomic definition of good yield) has often been used to delineate a good subgroup (Escano et al. 1981), using a spectrum of subgroups based on percentiles has not been investigated. All combinations of N, P, K, Ca, Mg, and DM ratios were formulated and F-tests were used to find the number of ratios that were different between subgroups at each diameter limit (Tables 5 and 6). (Appendix D contains the number of ratios for each subgroup for the other four tree factors measured.) The 90th percentile had the highest number of significant ratios (Table 5); at this diameter limit an acceptable proportion of the population represented good quality trees, making the reference population exclusive, but not too restrictive. Several authors have used this same criterion (maximizing the number of significant ratios in the proximity of 90% maximum yield) for delineating good versus poor populations (Jones 1981, Letzsch and Sumner 1984, and Kim and Leech 1986). The critical BD at the 90th percentile was 30 mm.

Table 6 contains the complete set of nutrient ratios that were used in this DRIS application. The statistics are for the 30 mm BD limit which corresponds to 90% of maximum BD. N/DM, P/DM, K/DM, Mg/DM, N/P, P/N, N/K, Ca/N, N/Mg, Mg/N, P/K, K/P, P/Mg, Mg/P, K/Mg, Mg/K, Ca/Mg, and Mg/Ca ratios were all significantly different between the "good" and "poor"

Table 5. Number of significant ratios and observations per basal diameter subgroups.

Percentile	Basal Diameter Limit	Number of Significant Ratios	Number of Observations Per High-/Low- Quality Subgroups
	- mm -		
95	32	16	5 / 103
90	30	18	11 / 97
85	29	7	16 / 92
80	27	12	23 / 85
75	27	12	27 / 81
70	26	12	32 / 76
65	25	11	39 / 69
60	24	12	45 / 63
55	24	14	48 / 60
50	23	15	55 / 53

Table 6. Statistics for nutrient ratios for high- and low -quality basal diameter subgroups of Fraser fir[1].

	High-Quality			Low-Quality			F-test[2]	T-test[3]
Ratio	Mean	Var.	CV	Mean	Var.	CV	Var. Ratio	p-value
N/DM	2.28	0.0065	3.53	2.20	0.0277	7.55	4.26***	0.0124
P/DM	0.23	0.0007	11.61	0.25	0.0009	12.24	ns	0.0217
K/DM	0.88	0.0032	6.45	0.81	0.0099	12.33	3.09*	0.0023
Ca/DM	0.38	0.0041	16.59	0.46	0.0031	12.13	ns	0.0001
Mg/DM	0.10	0.0001	10.59	0.13	0.0013	26.54	12.02***	0.0001
N/P	10.12	1.6885	12.79	8.92	1.3199	12.88	ns	0.0011
P/N	0.10	0.0002	14.47	0.11	0.0002	12.79	ns	0.0034
N/K	2.61	0.0356	7.23	2.76	0.1132	12.21	3.18**	0.0368
K/N	0.38	0.0008	7.17	0.37	0.0020	12.06	ns	0.2087
N/Ca	6.08	0.8644	15.30	4.86	0.4485	13.78	ns	0.0001
Ca/N	0.17	0.0007	15.40	0.21	0.0008	13.26	ns	0.0001
N/Mg	23.95	10.7174	13.98	17.98	33.3357	32.11	4.16**	0.0001
Mg/N	0.04	0.0000	10.92	0.06	0.0004	33.31	19.87***	0.0001
P/K	0.26	0.0009	11.62	0.31	0.0027	16.46	2.93*	0.0001
K/P	3.90	0.1649	10.42	3.27	0.2654	15.73	ns	0.0002
P/Ca	0.61	0.0170	21.40	0.55	0.0077	15.94	ns	0.1818
Ca/P	1.71	0.1174	20.06	1.86	0.0816	15.38	ns	0.1094
P/Mg	2.38	0.0976	13.13	2.02	0.3463	29.19	3.55**	0.0040
Mg/P	0.43	0.0029	12.62	0.54	0.0280	30.89	9.67***	0.0001
K/Ca	2.35	0.1921	18.66	1.80	0.1446	21.13	ns	0.0001
Ca/K	0.44	0.0064	18.19	0.58	0.0147	20.91	ns	0.0003
K/Mg	9.22	1.2548	12.15	6.65	5.6305	35.69	4.49**	0.0001
Mg/K	0.11	0.0002	12.00	0.17	0.0038	36.27	22.05***	0.0001
Ca/Mg	3.98	0.1648	10.20	3.67	0.9953	27.18	6.04***	0.0634
Mg/Ca	0.25	0.0007	10.70	0.29	0.0058	26.08	7.86***	0.0019

1. Number of observations in the high- and low-quality populations are 11 and 97 respectively.

2. F-tests labeled with *, **, *** denote significantly smaller ratio variances in the good population at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively.

3. T-tests with p-values ≤ 0.10 denote significant ratio mean differences.

subpopulations. As an example, Figure 2 depicts the variation difference between the "good" and "poor" populations in a plot of BD as a function of the N/K ratio. This scatter plot illustrates that trees with the largest BD occur when the nutrient ratios are within a relatively narrow range. The fact that the ratios of N, P, K, and Mg to DM are significantly different between subpopulations indicates that the intensity, or absolute level of these nutrients may also be limiting BD growth, as well as their relative level with other nutrients.

The discriminating nutrient ratios were incorporated into DRIS index equations for N, P, K, Ca, Mg, and DM determinations (Equations 8 - 15). These equations were based on Beaufils (1973) original formulations which have since been used in most DRIS applications.

$$Nindex = \frac{(fN/DM - fP/N + fN/K - fCa/N - fMg/N)}{5} \qquad [8]$$

$$Pindex = \frac{(fP/DM + fP/N + fP/K - fMg/P)}{4} \qquad [9]$$

$$Kindex = \frac{(fK/DM - fN/K - fP/K - fCa/K - fMg/K)}{5} \qquad [10]$$

$$Caindex = \frac{(fCa/N + fCa/K - fMg/Ca)}{3} \qquad [11]$$

$$Mgindex = \frac{(fMg/DM + fMg/N + fMg/P + fMg/K + fMg/Ca)}{5} \qquad [12]$$

$$DMindex = \frac{(-fN/DM - fP/DM - fK/DM - fMg/DM)}{4} \qquad [13]$$

where:

$$f(A/B) = (100\times[(A/B)/(a/b)] - 1)(k/CV) \qquad [14]$$

if a/b < A/B

$$f(A/B) = 100\times[1 - (a/b)/(A/B)](k/CV) \qquad [15]$$

if a/b > A/B

A/B is the ratio of nutrient *A* to nutrient *B* of the good population and a/b is the ratio of nutrient *A* to nutrient *B* of the poor population, CV is the coefficient of variation for the good population, and k is a constant that regulates the magnitude of the indices, and can be set at a convenient level.

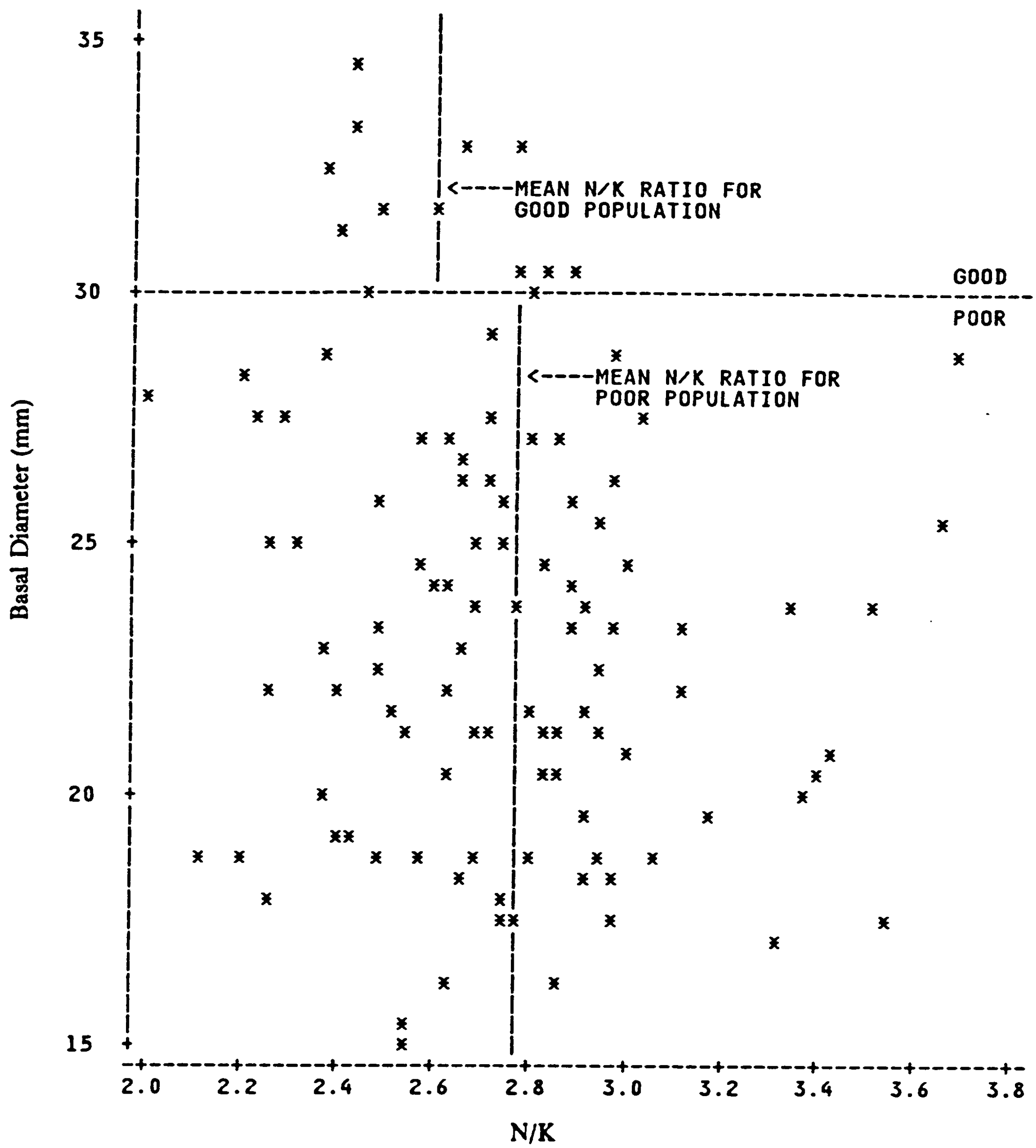

Figure 2. Scatter plot of basal diameter as a function of N/K ratio.

Conclusion

These preliminary equations are being used to test the efficacy of fertilizing young Fraser fir plantations based on BD response in the DRIS procedure. This study showed that major constraints in applying DRIS to Christmas trees, namely, identifying a suitable surrogate for yield, and having a basis for delineating good and poor population subgroups can be overcome.

The preliminary selection criteria established in this paper will be used in the development of a fertilizer prescription program for Fraser fir Christmas tree production. Now that the relationship between a tree response factor and nutrient status has been established, factorial fertilizer trials can be used to calibrate DRIS indices with a specific fertilizer amount that would alleviate nutrient deficiencies.

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A Case for Optimizing Nutrient Balance in Fraser Fir Christmas Trees.

Introduction

Techniques for diagnosing the nutrient status and responsiveness of Fraser fir Christmas trees to fertilizer applications are not very well developed. Many Fraser fir Christmas tree growers fertilize their plantations without knowing how or if their trees will respond. One grower may observe a desirable response to nitrogen only, while another may need to apply several nutrients in order to obtain a desirable response. The danger in applying fertilizer indiscriminately is that one or more added nutrients might affect overall tree nutrient balance in an adverse way. Correcting one deficiency may create another or cause an overall nutrient imbalance within the trees.

Young Fraser fir foliage appears to be very responsive to fertilizer inputs. Table 7 contains Fraser fir foliar concentrations of young trees from several sources: wild trees in their native environment on Mt. Rodgers, Virginia; preliminary critical levels established by the North Carolina State University Extension Laboratory (NCSUEL 1983); and foliar concentrations of unfertilized and fertilized trees in the same plantation of one of our cooperators in North Carolina. The data

Table 7. **Foliar nutrient levels for Fraser fir trees grown under various fertility levels.**

Nutrient Factor	Wild[1]	N.C. State[2]	Unfertilized	Fertilized[3]
	%			
N	1.39	1.75	2.18	2.26
P	0.07	0.18	0.24	0.25
K	0.43	0.60	0.83	0.76
Ca	0.11	0.60	0.43	0.47
Mg	0.03	0.10	0.13	0.27

1. Virginia Polytechnic Institute and State Univ., unpublished data.
2. N.C. State Soils Extension Lab (North Carolina State University Extension Laboratory 1983).
3. Fertilized annually with 324 kg/ha/yr 17-17-17 in spring and 437 kg/ha/yr DAP in fall.

show that compared to wild trees the nutrient concentration of trees under culture can be increased considerably. A comparison of the foliar nutrient levels in the wild trees with North Carolina State's foliar nutrient levels suggests that higher levels of all nutrients, than those that occur in wild trees, are desirable for producing Christmas trees. The nutrient levels in the unfertilized plantation suggest that trees growing in old fields may take advantage of residual nutrients or inherently more fertile soils, while slight increases in levels of the fertilized trees were associated with an overall increase in tree quality warranting the fertilizer investment as judged by this grower. This increase in quality probably had little to do with critical levels since all nutrients except calcium were well above the deficiency threshold. However, little is known about the importance of the balance of nutrient levels relative to each other, and whether or not nutrient balance elicits responses in Fraser fir Christmas tree quality.

The importance of nutrient balance was introduced by Shear et al. (1943). They contend that maximum growth and yield can only be achieved at optimum nutrient intensity and balance, and as nutrient contents change, the maximum growth possible under the new limits can only be accomplished when all other factors controlling nutrient supply and demand are brought into balance at the new levels of intensity. Ulrich (1962) pointed out that accounting for all nutrient contents and their interactions simultaneously was impractical given the level of diagnostic ability known at that time; however, new laboratory techniques and advances in statistics and computers provide substantially more powerful diagnostic alternatives. The Diagnosis and Recommendation Integrated System (DRIS) is a powerful nutrient diagnostic technique that has the advantage of diagnosing more than one limiting nutrient at a time (without pre-established critical levels), ranking the nutrients in order of need, and measuring nutrient intensity as well as balance among nutrients (Beaufils 1973). The status of nutritional balance can be monitored over several years as fertilizer is added to the soil, and multiple corrections can be made as needed.

A better understanding of Fraser fir diagnosis/fertilization/tree-response relationships are needed in order to economically prescribe fertilizers. The purposes of this study were to determine if Fraser fir Christmas tree quality and growth are a function of foliar nutrient balance, and whether or not nutrient balance can be manipulated with fertilizer applications.

Materials and Methods

The Fraser fir plantations used in this study were located on Bald Mountain (elev. 1340 m) in Watauga county, North Carolina. A multiple-factor Fraser fir Christmas tree fertilizer trial was established to study the effects of fertilizer treatments on Christmas tree development. Thirty-six different fertilization treatment combinations were applied on these sites to 108 thirty-tree plots. This trial created a plot by plot soil fertility gradient which in turn created a gradient in foliar nutrient concentrations and tree response factors.

Treatments in this fertilizer trial included two rates of N and P, two sources of N and P, a single rate of a balanced N, P, and K fertilizer, addition of lime and sulfur for pH adjustment, and three frequencies of fertilizer additions. Details of this fertilizer trial and long-term objectives are described by Kopp (1988). The trial, in this intermediate stage, was used in this study for the sole purpose of creating a gradient in tree response factors that could be correlated with foliar nutrient content. These plots, having received a variety of treatments, were considered analogous to separately-fertilized plantations in that each plot provided a representation of various fertilizer treatments and associated foliar nutrient intensities and balances. These plots were used as 108 separate experimental units for the purpose of this study.

In a previous study (Kopp, this volume), basal diameter (BD), was found to be a tree response factor that was nutrient-sensitive, responsive to fertilizer inputs, and representative of tree quality. Therefore, basal diameter was used to test the sensitivity of DRIS to foliar nutrient balance as manipulated by fertilizer treatments. Basal diameter (mm) was measured at ground level with calipers during the dormant season in the fall.

Foliar samples were analyzed for percent nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). Nitrogen was determined using Total Kjeldhal Nitrogen digestion procedures (Bremner 1965), and ammonia-salicylate colorimetric techniques on an autoanalyzer. Total P was determined using Murphy-Riley (1962) procedures on extracts of dry-ashed foliage samples. The dilute double acid method of Olsen and Dean (1965) was used to extract K, Ca, and Mg from the dry-ashed samples. Determinations were made on an atomic absorption spectrophotometer for K, Ca, and Mg. National Bureau of Standards (NBS 1979) pine needle tissue was used as a calibrant for all nutrients analyzed.

The SAS statistical analysis system (SAS Institute Inc. 1985) was used for all data handling. Standard DRIS methodology (Beaufils 1973) was used to calculate DRIS indices for each plot. High- and low- quality subgroups were formed by dividing the population at the 90th percentile; that is, 10% of the trees with the largest basal diameters were assigned to the high-quality subgroup. Ratios were considered discriminatory if either the variance or mean or both the variance and the mean of the two subgroups were significantly different. Neutral ratios (neither variances nor means were significant) were also used since some nutrients were not represented based on the above criteria. Beaufils and Sumner (1976) justified the use of neutral ratios by showing that a more accurate determination of nutritional balance is provided.

Nutrient balance index (NBI), the sum of the nutrient indices irrespective of sign (Sumner 1977), was also calculated for each plot. These NBIs were calculated using DRIS norms developed from foliar nutrient concentrations of a population of eighty 3-yr-old trees representing a wide range in tree quality and BD (Hockman 1986). These trees were located in plantations outside the study area.

To study the sensitivity of DRIS on 3-yr-old trees, six of the 108 plots representing a range of fertilizer treatments, were used as a preliminary independent test population to determine the extent to which nutrient balance can be manipulated with fertilizer. The remaining 102 plots were used to identify discriminating ratios on which to base the index equations. Stratified random sampling was used to pick each of the six test plots so that different fertilizer treatments were represented.

Results and Discussion

The means, variances, and coefficients of variation of all nutrient ratio combinations of N, P, K, Ca, and Mg and dry matter (DM) for the high- and low- quality subgroups were calculated based on the distribution of basal diameter measurements (Table 8). (Tables listing statistics for LL, NB, BE, and TQ are in Appendix E). Differences between subgroup nutrient ratio variances and means were delineated with F-tests and T-tests, respectively.

The data show that for these plantations, tree quality and growth is a function of both the amount (intensity) of nutrients in the foliage (nutrient/DM ratios) as well as the balance among nutrients. For example, BD was influenced by the intensity of N, P, K, and Mg in the foliage as demonstrated by the significance of nutrient/dry matter ratios. The importance of balance among nutrients to BD is illustrated by the number of nutrient ratios other than dry matter that were discriminating for BD and thus included in generating nutrient index equations (Equations 16 - 20). The N, K, and Mg index equations, for example, were a function of balance among all other nutrients (Equations 16, 18, and 20).

$$Nindex = \frac{(fN/DM - fP/N + fN/K - fCA/N - fMg/N)}{5} \qquad [16]$$

$$Pindex = \frac{(fP/DM + fP/N + fP/K - fMg/P)}{4} \qquad [17]$$

$$Kindex = \frac{(fK/DM - fN/K - fP/K - fCa/K - fMg/K)}{5} \qquad [18]$$

$$Caindex = \frac{(fCa/N + fCa/K - fMg/Ca)}{3} \qquad [19]$$

$$Mgindex = \frac{(fMg/DM + fMg/N + fMg/P + fMg/K + fMg/Ca)}{5} \qquad [20]$$

Further evidence that nutrient balance influences BD is shown by a scatter plot of BD as a function of the NBI (Figure 3). (Figures of scatter plots for LL, NB, BE and TQ as a function of

Table 8. Statistics for nutrient ratios for high- and low-quality basal diameter subgroups of Fraser fir[1].

	High-Quality			Low-Quality			F-test[2]	T-test[3]
Ratio	Mean	Var.	CV	Mean	Var.	CV	Var. Ratio	p-value
N/DM	2.28	0.0067	3.60	2.19	0.0277	7.58	4.12**	0.0163
P/DM	0.23	0.0007	11.40	0.25	0.0009	12.20	ns	0.0680
K/DM	0.88	0.0034	6.63	0.81	0.0104	12.62	3.03*	0.0029
Ca/DM	0.38	0.0045	17.51	0.46	0.0030	12.07	ns	0.0002
Mg/DM	0.10	0.0001	11.14	0.13	0.0013	27.18	11.48	0.0001
N/P	10.01	1.5927	12.61	8.93	1.3303	12.91	ns	0.0066
P/N	0.11	0.0002	14.18	0.11	0.0002	12.86	ns	0.0133
N/K	2.59	0.0358	7.31	2.75	0.1184	12.50	3.30*	0.0328
K/N	0.39	0.0008	7.15	0.37	0.0021	12.29	ns	0.1948
N/Ca	6.09	0.9584	16.07	4.87	0.4606	13.94	ns	0.0033
Ca/N	0.17	0.0007	16.23	0.21	0.0008	13.41	ns	0.0001
N/Mg	23.98	8.8820	12.43	17.98	35.0692	32.94	3.95**	0.0001
Mg/N	0.04	0.0000	11.51	0.06	0.0004	33.93	18.75***	0.0001
P/K	0.26	0.0010	11.80	0.31	0.0027	16.65	2.84*	0.0004
K/P	3.87	0.1718	10.72	3.28	0.2700	15.81	ns	0.0009
P/Ca	0.62	0.0176	21.47	0.55	0.0077	15.91	ns	0.1480
Ca/P	1.68	0.1224	20.79	1.86	0.0817	15.39	ns	0.0740
P/Mg	2.42	0.0928	12.61	2.01	0.3620	29.91	3.90**	0.0024
Mg/P	0.42	0.0026	12.27	0.54	0.0292	31.33	11.00***	0.0001
K/Ca	2.37	0.2081	19.25	1.81	0.1499	21.44	ns	0.0001
Ca/K	0.44	0.0070	19.16	0.58	0.0153	21.38	ns	0.0006
K/Mg	9.29	1.2209	12.42	6.66	5.9392	36.54	4.46	0.0001
Mg/K	0.11	0.0002	12.49	0.17	0.0040	37.04	21.69***	0.0001
Ca/Mg	3.98	0.1832	10.75	3.66	1.0382	27.83	5.67***	0.0779
Mg/Ca	0.25	0.0008	11.26	0.29	0.0060	26.42	7.34***	0.0013

1. Number of observations in the high- and low-quality populations are 10 and 92 respectively.
2. F-tests labeled with *, **, *** denote significantly smaller ratio variances in the good population at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively.
3. T-tests with p-values < 0.10 denote significant ratio mean differences.

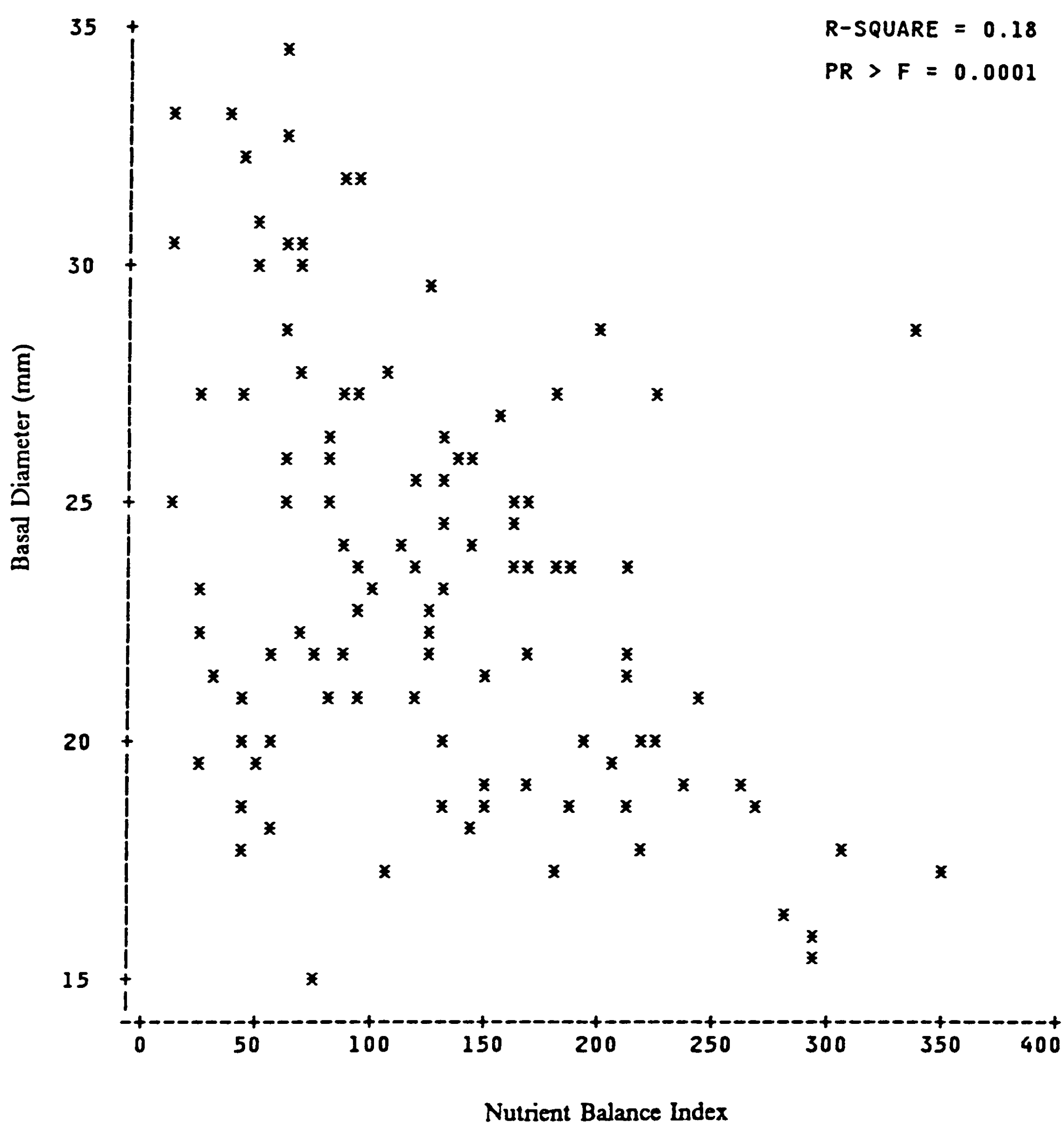

Figure 3. Scatter plot of basal diameter as a function of the nutrient balance index.

NBI are shown in Appendix F). This plot shows that large basal diameter trees are produced only when NBI has a relatively small value. As NBI values increase, maximum basal diameters decrease. Trees with relatively small NBI values and small basal diameters were adversely affected by factors other than nutrient intensity or balance.

The sensitivity of DRIS to fertilizer inputs can be seen in Table 9. Along with DRIS indices, NBI, BD, and N, P, K, Ca, and Mg foliar nutrient concentrations for these 3-yr-old plantations are listed for each of the six test plots. (Appendix G contains the same tables for LL, NB, BE, and TQ). Except for Ca, the foliar nutrient concentrations of trees in plot 1, which received no fertilizer, were above the suggested foliar levels (Table 7). This shows that the residual fertility of the soils on these plots was already high, which is confirmed by the negative DM indices (deficient DM relative to foliar nutrient concentrations) in all but plot 2. However, fertilizer inputs increased BD above the control plot suggesting that nutrient intensity and/or balance was not at optimal levels for growth and development.

Although plot 2 was the most balanced as indicated by the lowest NBI, and the largest BD, this plot could possibly do even better if it was supplied with the deficient nutrients as is indicated by its positive DM index. Plots 3, and 4, had trees with nutrient imbalances aggravated particularly by high foliar Mg levels that were caused by inherently high soil levels (as is shown by the relatively high foliar Mg concentrations, Mg indices, and NBI, with a corresponding decrease in BD).

Both plots 5 and 6 had lower BDs than the other fertilized plots. Plot 5 had the second lowest NBI, but had a K imbalance and a relatively low K concentration, despite the addition of K fertilizer. In plot 6 where Mg was applied as lime, trees also had a relatively low K concentration, but the K index was even lower, with a corresponding excess of Mg. Low supplies of K from the soil may result in excessive Mg levels in the tissue (Mengel and Kirkby 1982). Although Mg foliar levels in plots 5 and 6 are not at the highest levels, foliar K levels are the lowest of the six plots studied. If nutrient balance is just as important as nutrient intensity, then trees in plots 5 and 6 are imbalanced relative to K. All plots show some degree of K deficiency, but the fertilizer amounts added in plots 5 and 6 further aggravated the K imbalance.

Table 9. BD, DRIS indices, NBI, and foliar nutrient concentrations as affected by fertilizer treatments.

Plot No.	Fertilizer Treatment N	P	K	Ca	Mg	Basal Diameter	DRIS Indices N	P	K	Ca	Mg	DM	Nutrient Balance Index	Nutrient Concentration N	P	K	Ca	Mg
	kg/ha/yr					- mm -								%				
1	0	0	0	0	0	20	-1	-6	-15	8	28	-15	72	2.48	0.24	0.87	0.51	0.14
2	86	0	0	0	0	30	5	-12	-3	1	5	3	29	2.35	0.20	0.84	0.39	0.10
3	0	67	0	0	0	26	-12	18	-18	-4	29	-14	96	2.30	0.30	0.85	0.42	0.14
4	86	67	0	0	0	26	-15	5	-17	20	25	-12	93	2.31	0.26	0.87	0.58	0.14
5	134	111	87	0	0	23	-3	10	-21	14	11	-4	64	2.34	0.26	0.79	0.49	0.11
6	134	111	87	982	491	25	-11	23	-29	14	21	-10	107	2.31	0.30	0.78	0.51	0.13

Conclusion

These analyses suggested that nutrient intensity and balance are equally important for optimal Fraser fir growth and development. The importance of nutrient intensity was shown since four nutrient/dry matter ratios were discriminating for BD. Balance was shown to be important since all the DRIS indices were a function of at least three nutrient ratios, and N, K, and Mg were a function of all significant nutrient ratios. The significant relationship between NBI and BD also supported the importance of nutrient balance. Only when NBI had a relatively small value were large BDs produced. In general, as NBI increased, BD decreased. Finally, although foliar K was above the suggested NCSUEL level, its imbalance with Mg seemed to retard BD growth, although, in one case NBI was relatively small and in the other case it was rather large. These results suggest that nutrient balance in Fraser fir as well as adequate nutrient intensity must be achieved by fertilizer prescriptions for optimal Fraser fir Christmas tree growth and development.

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Summary

Competition in the Fraser fir Christmas tree industry has forced growers to produce high-quality trees in order to stay in business. Important cultural techniques such as herbiciding, mowing, and shearing are reasonably known and readily prescribed, but the techniques of nutrient assessment and applying fertilizers to correct deficiencies are not well understood. If other cultural techniques are applied at their optimal levels, then tree nutrition becomes an important factor in maximizing Christmas tree quality. Comparing the foliar nutrient contents of wild trees to cultivated trees shows that Fraser fir responds to fertilizer inputs; however, the biology and economics of this response is not well understood; and diagnostic procedures that might be used to assess the nutrient status of this species has not been investigated. The agricultural industry has a well developed fertilizer prescription program based on yield (kg/ha); however, Christmas tree production is based on tree quality rather than total yield or production. Three problems impeded the development of a fertilizer prescription program for Fraser fir Christmas trees: 1) identifying a suitable tree response factor as a surrogate for yield; 2) delineating between high- and low- quality trees; and 3) relating tree responses to nutrient balance and applied fertilizer. This study helped solve these problems thereby helping to lay the foundation for developing an effective fertilizer prescription program for Fraser fir Christmas trees.

A nutrient-sensitive tree response factor related to nutrient balance and influenced by fertilizer treatments was needed to serve as a diagnostic indicator of tree vigor and quality. Basal diameter met these criteria. Large basal diameter trees were associated with high nutrient intensity (concentration), optimal nutritional balance, and high-quality trees while fertilizer inputs, which altered nutrient intensity and balance, also affected basal diameter, sometimes in adverse ways. A nutrient diagnostic technique that related basal diameter to nutritional status and quantified nutrient deficiencies was needed to analyze the effects of fertilizer inputs on nutrient intensity and balance. The Diagnosis and Recommendation Integrated System (DRIS) was used to compare the foliar nutrient status of high-quality (good-yielding) populations to that of low-quality (low-yielding) populations. In this case foliar nutrient intensity and balance of large basal diameter trees were compared to that of smaller basal diameter trees. The results showed that high-quality trees were produced only when foliar nutrients were at optimal intensity and balance, although optimal intensity and balance did not always produce high-quality trees because other factors were limiting BD growth.

These preliminary results will be the basis for an expanded investigation for developing a Fraser fir Christmas tree fertilization prescription program. In the small population of trees used in this study, significant relationships were found between tree quality (basal diameter) and foliar nutrient status (intensity and balance). Now that these relationships have been quantified, further research focused on expanding the data base to increase the diagnostic spectrum of the prescription program is needed. The preliminary DRIS equations calculated for this study are applicable only to the specific plantations on which they were based. By obtaining observations consisting of high-quality (large basal diameter) trees with their associated nutrient status from all conditions to which Fraser fir Christmas trees are exposed, the preliminary DRIS equations can be refined to diagnose Fraser fir nutrient deficiencies on a broader scale. Factorial fertilizer trials would then be used to calibrate DRIS indices with specific fertilizer amounts that would alleviate deficiencies. If nutrient status was the only factor limiting tree quality development, then corrective fertilizer applications would improve tree quality. Although a complete fertilizer prescription program is several years in the future, the quantification of tree quality and its correlation with nutrient status lays the foundation for continuing the development of such a program.

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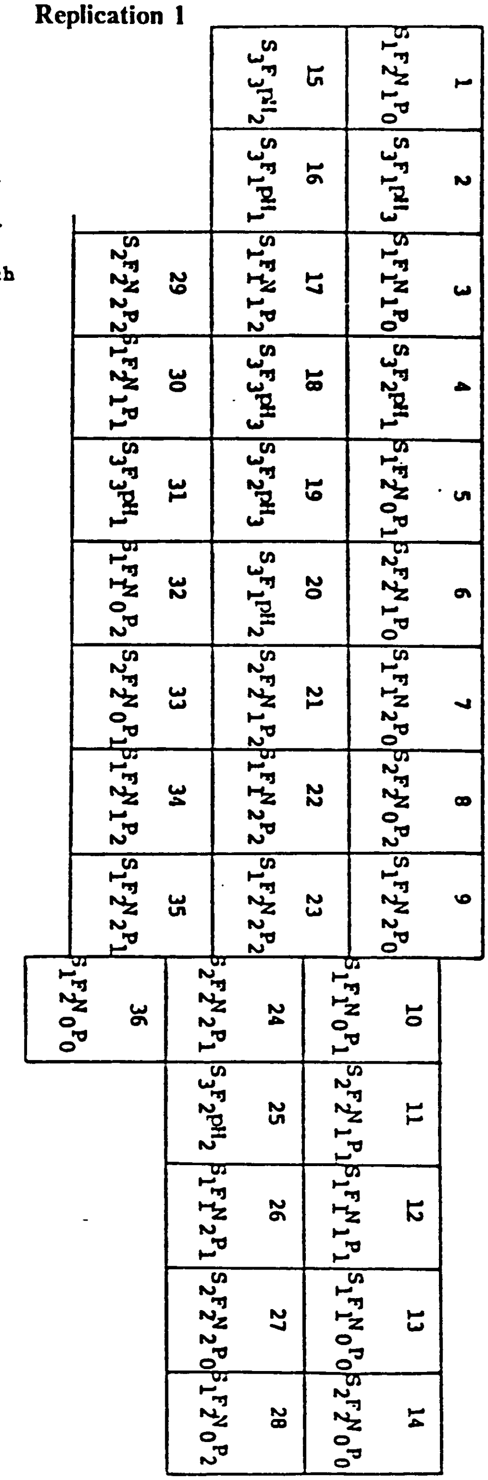
Appendix A. Fraser Fir Fertilizer Study Maps

Appendix A-1

Replication 1

Map of Replication #1 of the Fertilizer Trial installed May 1984 as part of the VPI & SU-H. Smith Richardson Trust Research Project.

This replication is located immediately to the southwest of the equipment shed at an elevation of 4400' and S 50° E aspect and a 15% slope. It is also located on the Wautaga loam (eroded rolling phase).



Appendix A-2

Replication 2

Map of Replication #2 of the Fertilization Trial installed May 1984 as part of the VPI & SU - H. Smith Richardson Trust Research Project.

1 $S_2F_2N_2P_1$	2 $S_2F_2N_0P_1$	3 $S_1F_2N_2P_0$	4 $S_1F_2N_0P_1$	5 $S_2F_2N_2P_0$	6 $S_3F_1pH_1$
7 $S_1F_2N_0P_0$	8 $S_3F_2pH_2$	9 $S_3F_2pH_3$	10 $S_3F_3pH_3$	11 $S_3F_1pH_2$	12 $S_1F_2N_1P_0$
13 $S_1F_1N_2P_1$	14 $S_2F_2N_1P_1$	15 $S_3F_2pH_1$	16 $S_1F_2N_2P_1$	17 $S_1F_2N_1P_2$	18 $S_1F_2N_2P_2$
19 $S_1F_2N_0P_2$	20 $S_3F_3pH_2$	21 $S_1F_1N_1P_0$	22 $S_2F_2N_1P_0$	23 $S_1F_1N_0P_1$	24 $S_1F_1N_0P_2$
25 $S_1F_1N_0P_0$	26 $S_1F_2N_1P_1$	27 $S_1F_1N_2P_2$	28 $S_3F_3pH_1$	29 $S_1F_1N_1P_2$	30 $S_2F_2N_2P_2$
31 $S_1F_1N_2P_0$	32 $S_2F_2N_0P_0$	33 $S_1F_1N_1P_1$	34 $S_2F_2N_0P_2$	35 $S_2F_2N_1P_2$	36 $S_3F_1pH_3$

This replication is located on a side slope position on the northern protion of Long Hope mountain adjacent to Ashe-Wautaga County line. The elevation is 4500' with an aspect of N 30° E, on a 35 - 45% slope. It is also located on the Watauga stony loam (rolling phase) and is down-slope from Replication #3.

Appendix A-3

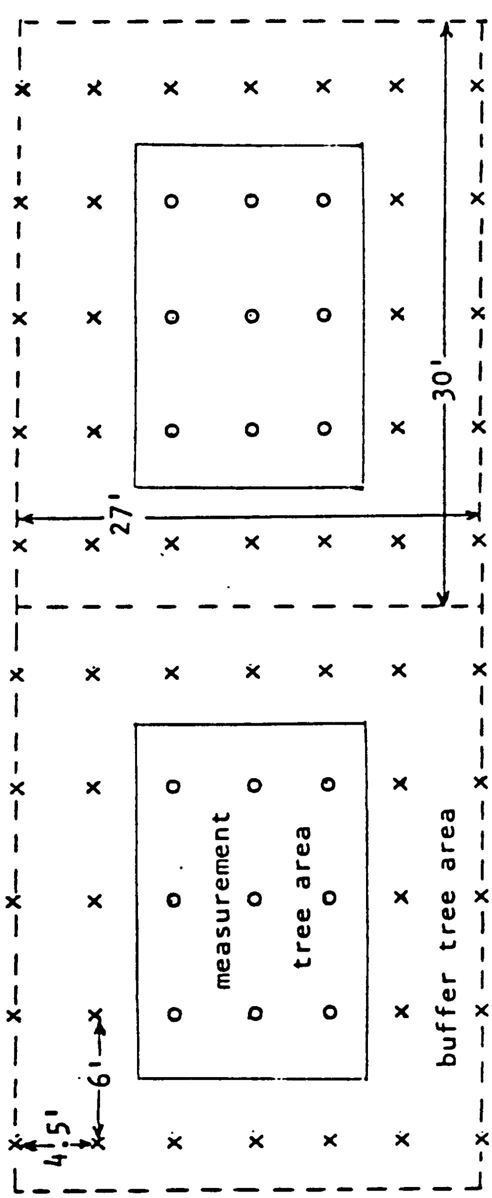
Replication 3

Map of Replication #3 of the Fertilization Trial installed May 1984 as part of the VPI & SU - H. Smith Richardson Trust Research Project.

1 $S_1F_2N_2P_2$	2 $S_1F_2N_1P_0$	3 $S_2F_2N_0P_1$	4 $S_1F_1N_0P_2$	5 $S_3F_2pH_3$	6 $S_1F_1N_1P_2$
7 $S_1F_2N_2P_0$	8 $S_2F_2N_0P_2$	9 $S_1F_1N_2P_1$	10 $S_1F_1N_0P_0$	11 $S_3F_2pH_1$	12 $S_1F_2N_2P_1$
13 $S_2F_2N_1P_1$	14 $S_1F_2N_0P_2$	15 $S_1F_2N_1P_1$	16 $S_1F_1N_2P_2$	17 $S_1F_1N_1P_1$	18 $S_2F_2N_2P_0$
19 $S_3F_1pH_3$	20 $S_2F_2N_1P_0$	21 $S_1F_2N_1P_2$	22 $S_1F_1N_0P_1$	23 $S_2F_2N_2P_2$	24 $S_1F_2N_0P_1$
25 $S_3F_1pH_2$	26 $S_1F_2N_0P_0$	27 $S_1F_1N_2P_0$	28 $S_3F_3pH_1$	29 $S_3F_3pH_2$	30 $S_3F_2pH_2$
31 $S_3F_1pH_1$	32 $S_2F_2N_0P_0$	33 $S_2F_2N_2P_1$	34 $S_3F_3pH_3$	35 $S_1F_1N_1P_0$	36 $S_2F_2N_1P_2$

This replication is located on a side slope position on the northern portion of Long Hope Mountain adjacent to Ashe-Wautaga County line. The elevation is 4500' with an aspect of N 30° E on a 35 - 45% slope. It is also located on the Watauga stony loam (rolling phase) and is up-slope from Replication #2.

Appendix B. Plot Layout



x = buffer tree

o = measurement tree

- - - = treatment boundary

—— = measurement (sample) area boundary

Appendix C. Fertilizer Types and Rates

Equations for calculating fertilizer amount per tree

NH_4NO_3

N1 = 48 lb N/ac

(48 lb N/ac)×(ac/1613 trees)×(16 oz/lb)×(NH₄NH&sub3/.34 N) =

1.40 oz NH_4NO_3/tree

N2 = 2.4 oz/tree (96 lb N/ac)

Osmocote

N1 = 48 lb N/ac

(48 lb N/ac)×(ac/1613 trees)×(16 oz/lb)×(Osmocote/.39 N) =

1.2 oz Osmocote/tree

N2 = 2.4 oz/tree (96 lb N/ac)

TSP

P1 = 75 lb P/ac

(75 lb P/ac)×(ac/1613 trees)×(16 oz/lb)×(TSP/.46 P_2O_5)×(P_2O_5/.43 P) =

3.75 oz TSP/tree

P2 = 7.50 oz/tree (150 lb P/ac)

GRP

P1 = 75 lb P/ac

(75 lb P/ac)×(ac/1613 trees)×(16 oz/lb)× (GRP/.20 P_2O_5)×(P_2O_5/.43 P) =

8.65 oz GRP/tree

P2 = 17.30 oz/tree (150 lb P/ac)

KCL 2.0 oz/tree for all plots.

NPK (17-17-17)

Amount depends on plantation age

Age	oz/tree
3	1.5
4	2.0
5	2.5
6	3.0
7	2.0
8	2.0

DAP

Amount was based on Gentry's recommendation rate as per N.C. State rates.

2.70 oz/tree

Lime (90% CCE)

As per SMP by Hockman.

Replication one (4.5 tons/ac)×(ac/1613 trees)×(2000 lb/ton)×(16 oz/tree)×(1/.90) =

99.2 oz Lime/tree

Replication two (5.5 tons/ac)×(ac/1613 trees)×(2000 lb/ton)×(16 oz/tree)×(1/.90) =

121.0 oz Lime/tree

Sulfur

Hockman used the VPI&SU Extension publication "Lime of Acid Agronomic Soils"

(960 lb S/ac)&mult(ac/1613 trees)×(16 oz/lb) =

(9.5 oz/tree)

Appendix D. Tables of Number of Significant Ratios and Observations

Appendix D-1

Number of significant ratios and observations per leader length subgroups.

Percentile	Diameter Limit	Number of Significant Ratios	Number of Observations Per High-/Low- Qualtiy Subgroup
	- cm -		
95	29.11	13	5 / 103
90	26.33	20	11 / 97
85	24.44	19	17 / 91
80	23.33	20	22 / 86
75	20.56	17	27 / 81
70	19.67	18	31 / 77
65	17.78	12	38 / 70
60	17.44	13	44 / 64
55	16.67	11	49 / 59
50	15.33	10	55 / 53

Appendix D-2

Number of significant ratios and observations per number of buds subgroups.

Percentile	Diameter Limit	Number of Significant Ratios	Number of Observations Per High-/Low- Qualtiy Subgroup
95	27.44	7	6 / 102
90	24.00	11	10 / 98
85	22.50	14	17 / 91
80	21.50	15	22 / 86
75	20.11	17	28 / 80
70	19.11	15	33 / 75
65	18.33	11	39 / 69
60	17.44	15	44 / 64
55	15.89	11	49 / 59
50	15.00	12	54 / 54

Appendix D-3

Number of significant ratios and observations per bud elongation subgroups.

Percentile	Diameter Limit	Number of Significant Ratios	Number of Observations Per High-/Low- Quality Subgroup
95	14.56	13	5 / 103
90	12.89	14	10 / 98
85	11.00	10	16 / 92
80	10.11	11	22 / 86
75	8.89	10	27 / 81
70	7.67	8	37 / 71
65	7.44	9	39 / 69
60	6.89	9	43 / 65
55	6.33	13	50 / 58
50	6.00	12	55 / 53

Appendix D-4

Number of significant ratios and observations per tree quality index subgroups [1].

Percentile	Diameter Limit	Number of Significant Ratios	Number of Observations Per High-/Low- Quality Subgroup
90	1.44	3	2 / 106
80	1.56	3	20 / 88
70	1.67	2	26 / 82
60	1.78	9	44 / 64
50	1.89	2	58 / 50

1. Because index divisions were so close together, a factor of 10 rather than 5 was used to delineate percentile limits.

Appendix E. Tables of DRIS Statistics

Appendix E-1

Statistics for nutrient ratios for high- and low-quality leader length subgroups of Fraser fir[1].

	High-Quality			Low-Quality			F-test[2]	T-test[3]
Ratio	Mean	Var.	CV	Mean	Var.	CV	Var. Ratio	p-value
N/DM	2.27	0.0088	4.13	2.18	0.0296	7.87	3.38***	0.0035
P/DM	0.24	0.0007	10.89	0.25	0.0010	12.64	ns	0.3923
K/DM	0.88	0.0036	6.84	0.80	0.0106	12.89	2.92***	0.0001
Ca/DM	0.39	0.0036	15.33	0.47	0.0025	10.64	ns	0.0001
Mg/DM	0.10	0.0002	15.30	0.14	0.0012	25.33	5.67***	0.0001
N/P	9.48	1.3840	12.40	8.91	1.4068	13.31	ns	0.0479
P/N	0.11	0.0002	12.70	0.11	0.0002	13.21	ns	0.0483
N/K	2.59	0.0555	9.09	2.78	0.1215	12.56	2.19**	0.0063
K/N	0.39	0.0012	8.99	0.37	0.0021	12.41	ns	0.0324
N/Ca	5.92	0.6581	13.71	4.73	0.3298	12.13	ns	0.0001
Ca/N	0.17	0.0005	13.59	0.21	0.0007	11.90	ns	0.0001
N/Mg	24.00	13.7518	15.45	17.07	31.4057	32.82	2.28**	0.0001
Mg/N	0.04	0.0000	15.67	0.06	0.0004	32.24	9.81***	0.0001
P/K	0.27	0.0012	12.60	0.32	0.0029	16.92	2.35**	0.0001
K/P	3.67	0.1893	11.86	3.25	0.2807	16.29	ns	0.0010
P/Ca	0.63	0.0116	17.03	0.54	0.0064	14.88	ns	0.0001
Ca/P	1.63	0.0695	16.20	1.90	0.0768	14.59	ns	0.0001
P/Mg	2.54	0.1213	13.69	1.91	0.3274	29.87	2.70**	0.0001
Mg/P	0.40	0.0045	16.66	0.57	0.0284	29.61	6.34***	0.0001
K/Ca	2.31	0.1906	18.90	1.74	0.1107	19.14	ns	0.0001
Ca/K	0.45	0.0077	19.57	0.60	0.0139	19.75	ns	0.0001
K/Mg	9.30	2.1590	15.80	6.27	5.1930	36.35	2.41**	0.0001
Mg/K	0.11	0.0003	16.77	0.18	0.0039	34.79	11.53***	0.0001
Ca/Mg	4.11	0.6263	19.24	3.58	0.9987	27.94	ns	0.0220
Mg/Ca	0.25	0.0021	18.11	0.30	0.0061	26.07	2.96***	0.0004

1. Number of observations in the high- and low-quality populations are 22 and 80 respectively.

2. F-tests labeled with *, **, *** denote significantly smaller ratio variances in the good population at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively.

3. T-tests with p-values ≤ 0.10 denote significant ratio mean differences.

Statistics for nutrient ratios for high- and low-quality number of buds subgroups of Fraser fir[1].

	High-Quality			Low-Quality			F-test[2]	T-test[3]
Ratio	Mean	Var.	CV	Mean	Var.	CV	Var. Ratio	p-value
N/DM	2.27	0.0068	3.64	2.18	0.0310	8.08	4.54***	0.0005
P/DM	0.24	0.0008	11.24	0.25	0.0010	12.70	ns	0.6436
K/DM	0.88	0.0061	8.92	0.79	0.0099	12.55	ns	0.0002
Ca/DM	0.42	0.0060	18.48	0.46	0.0023	10.49	ns	0.0090
Mg/DM	0.10	0.0004	20.47	0.14	0.0012	25.14	2.90***	0.0001
N/P	9.40	1.3778	12.49	8.90	1.4209	13.38	ns	0.0662
P/N	0.11	0.0002	12.82	0.11	0.0002	13.25	ns	0.0638
N/K	2.62	0.0934	11.68	2.78	0.1135	12.12	ns	0.0324
K/N	0.39	0.0017	10.56	0.36	0.0020	12.12	ns	0.0309
N/Ca	5.60	0.8978	16.91	4.77	0.3622	12.62	ns	0.0001
Ca/N	0.18	0.0010	17.23	0.21	0.0007	12.26	ns	0.0001
N/Mg	23.33	20.8039	19.55	16.85	30.0348	32.52	ns	0.0001
Mg/N	0.04	0.0001	20.25	0.07	0.0004	32.16	5.49***	0.0001
P/K	0.28	0.0017	14.66	0.32	0.0028	16.79	ns	0.0025
K/P	3.62	0.2236	13.07	3.24	0.2780	16.25	ns	0.0016
P/Ca	0.60	0.0106	17.11	0.54	0.0075	16.01	ns	0.0053
Ca/P	1.71	0.0869	17.22	1.89	0.0804	15.02	ns	0.0075
P/Mg	2.49	0.1658	16.36	1.89	0.3229	30.01	1.95*	0.0001
Mg/P	0.41	0.0062	19.00	0.57	0.0289	29.55	4.67***	0.0001
K/Ca	2.18	0.2330	22.16	1.75	0.1166	19.54	ns	0.0001
Ca/K	0.48	0.0167	26.66	0.59	0.0131	19.28	ns	0.0001
K/Mg	9.02	3.4814	20.69	6.17	4.8927	35.86	ns	0.0001
Mg/K	0.12	0.0011	28.15	0.18	0.0039	34.26	3.61***	0.0001
Ca/Mg	4.22	0.7071	19.93	3.50	0.9252	27.46	ns	0.0009
Mg/Ca	0.24	0.0021	18.66	0.30	0.0060	25.33	2.85***	0.0001

1. Number of observations in the high- and low-quality populations are 27 and 75 respectively.
2. F-tests labeled with *, **, *** denote significantly smaller ratio variances in the good population at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively.
3. T-tests with p-values ≤ 0.10 denote significant ratio mean differences.

Statistics for nutrient ratios for high- and low-quality bud elongation subgroups of Fraser fir[1].

	High-Quality			Low-Quality			F-test[2]	T-test[3]
Ratio	Mean	Var.	CV	Mean	Var.	CV	Var. Ratio	p-value
N/DM	2.29	0.0 35	2.59	2.19	0.0279	7.62	7.93***	0.0004
P/DM	0.25	0.0009	11.67	0.25	0.0009	12.40	ns	0.4433
K/DM	0.85	0.0113	12.48	0.81	0.0100	12.32	ns	0.2006
Ca/DM	0.43	0.0044	15.46	0.45	0.0035	13.12	ns	0.2209
Mg/DM	0.10	0.0002	13.35	0.13	0.0013	27.36	7.62***	0.0001
N/P	9.14	1.2159	12.06	9.02	1.4838	13.50	ns	0.7655
P/N	0.11	0.0002	11.41	0.11	0.0002	13.55	ns	0.6723
N/K	2.73	0.1209	12.75	2.74	0.1125	12.25	ns	0.9215
K/N	0.37	0.0019	11.64	0.37	0.0020	12.02	ns	0.9397
N/Ca	5.46	0.7642	16.01	4.93	0.5957	15.65	ns	0.0366
Ca/N	0.19	0.0008	15.22	0.21	0.0009	14.52	ns	0.0379
N/Mg	23.53	12.2367	14.87	17.97	35.2297	33.03	2.88	0.0003
Mg/N	0.04	0.0000	14.38	0.06	0.0004	34.03	11.52***	0.0001
P/K	0.30	0.0018	13.92	0.31	0.0029	17.44	ns	0.6559
K/P	3.38	0.2061	13.42	3.34	0.3008	16.43	ns	0.7939
P/Ca	0.60	0.0080	14.85	0.55	0.0089	17.03	ns	0.1104
Ca/P	1.70	0.0697	15.53	1.86	0.0875	15.92	ns	0.0935
P/Mg	2.59	0.1382	14.35	1.99	0.3366	29.22	ns	0.0011
Mg/P	0.39	0.0033	14.56	0.55	0.0283	30.61	8.62***	0.0001
K/Ca	2.04	0.1794	20.80	1.84	0.1801	23.06	ns	0.1508
Ca/K	0.51	0.0140	23.11	0.57	0.0163	22.35	ns	0.1516
K/Mg	8.80	3.6728	21.78	6.69	5.9293	36.37	ns	0.0069
Mg/K	0.12	0.0007	22.50	0.17	0.0041	37.50	5.75	0.0001
Ca/Mg	4.36	0.4854	15.98	3.61	0.9633	27.17	ns	0.0161
Mg/Ca	0.23	0.0010	13.72	0.30	0.0058	25.65	5.61***	0.0001

1. Number of observations in the high- and low-quality populations are 11 and 91 respectively.
2. F-tests labeled with *, **, *** denote significantly smaller ratio variances in the good population at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively.
3. T-tests with p-values ≤ 0.10 denote significant ratio mean differences.

Appendix E-4

Statistics for nutrient ratios for high- and low- tree quality index subgroups of Fraser fir[1].

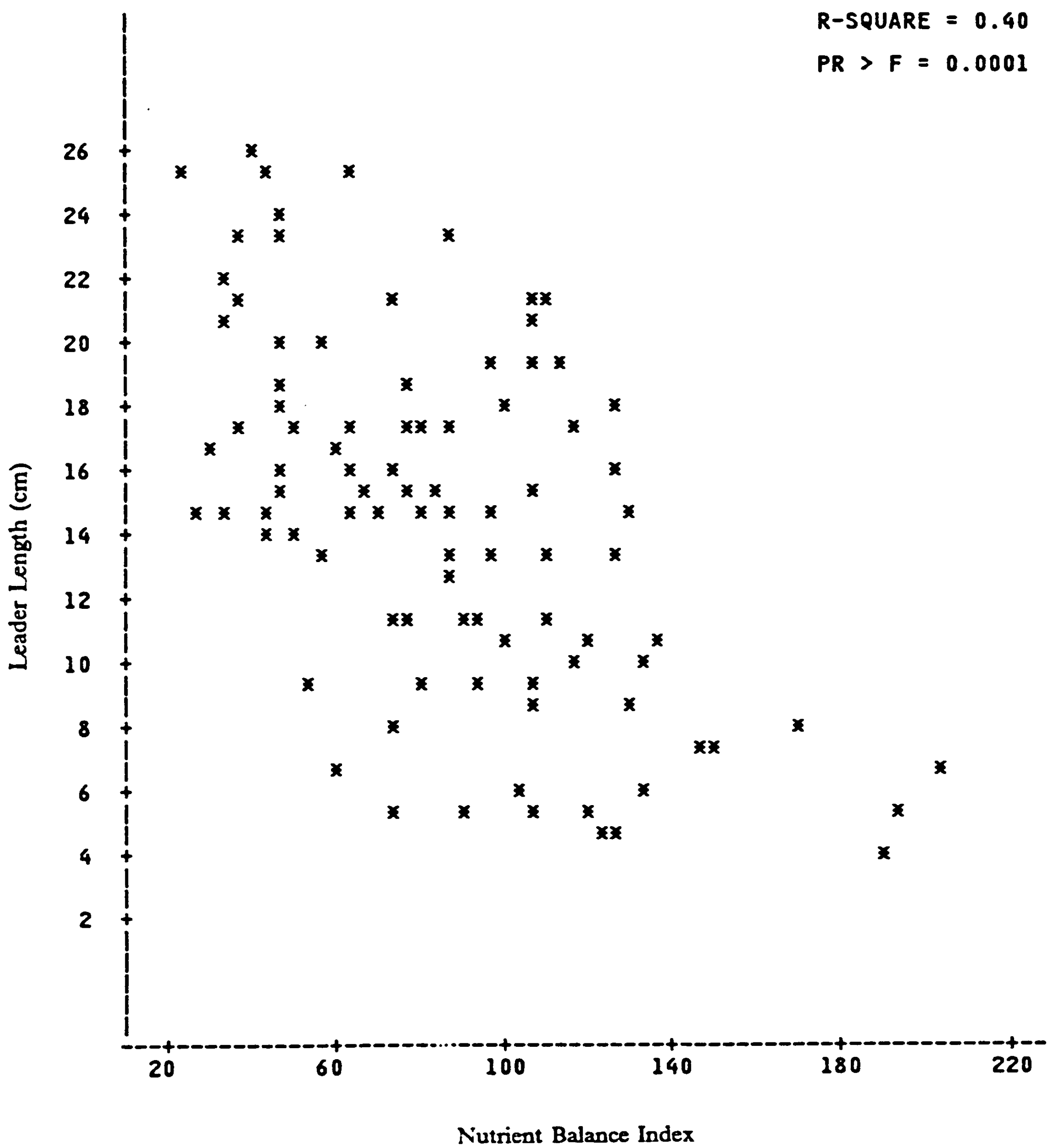
	High-Quality			Low-Quality			F-test[2]	T-test[3]
Ratio	Mean	Var.	CV	Mean	Var.	CV	Var. Ratio	p-value
N/DM	2.22	0.0263	7.30	2.19	0.0261	7.38	ns	0.3385
P/DM	0.25	0.0009	12.22	0.25	0.0009	12.44	ns	0.8782
K/DM	0.84	0.0111	12.50	0.80	0.0089	11.86	ns	0.0279
Ca/DM	0.44	0.0052	16.38	0.45	0.0025	11.08	ns	0.3027
Mg/DM	0.12	0.0011	27.17	0.14	0.0014	27.68	ns	0.0354
N/P	9.13	1.4896	13.36	8.97	1.4270	13.31	ns	0.5134
P/N	0.11	0.0002	13.33	0.11	0.0002	13.37	ns	0.5147
N/K	2.67	0.1192	12.92	2.77	0.1050	11.67	ns	0.1260
K/N	0.38	0.0022	12.26	0.36	0.0018	11.47	ns	0.0937
N/Ca	5.17	0.9442	18.79	4.87	0.3991	12.98	ns	0.0801
Ca/N	0.20	0.0014	18.42	0.21	0.0006	11.98	ns	0.1891
N/Mg	19.79	30.4445	27.87	17.74	37.9242	34.71	ns	0.0821
Mg/N	0.05	0.0004	34.50	0.06	0.0005	34.11	ns	0.0596
P/K	0.30	0.0022	15.82	0.31	0.0030	17.40	ns	0.0871
K/P	3.45	0.2752	15.20	3.26	0.2886	16.44	ns	0.0907
P/Ca	0.57	0.0121	19.24	0.55	0.0067	14.93	ns	0.2507
Ca/P	1.81	0.1153	18.74	1.86	0.0691	14.13	ns	0.4332
P/Mg	2.16	0.2843	24.36	1.97	0.3834	31.36	ns	0.1117
Mg/P	0.49	0.0215	29.62	0.56	0.0310	31.57	ns	0.0622
K/Ca	1.98	0.2555	25.54	1.78	0.1201	19.44	ns	0.0329
Ca/K	0.54	0.0207	26.70	0.58	0.0128	19.41	ns	0.1140
K/Mg	7.55	5.5982	31.35	6.50	6.0518	37.83	ns	0.0354
Mg/K	0.15	0.0033	38.39	0.18	0.0042	36.89	ns	0.0288
Ca/Mg	3.82	0.7406	22.52	3.61	1.1044	29.15	ns	0.2776
Mg/Ca	0.27	0.0037	22.16	0.30	0.0067	27.41	1.82**	0.0800

1. Number of observations in the high- and low-quality populations are 41 and 61 respectively.
2. F-tests labeled with *, **, *** denote significantly smaller ratio variances in the good population at $P \leq 0.10$, $P \leq 0.05$, and $P \leq 0.01$, respectively.
3. T-tests with p-values ≤ 0.10 denote significant ratio mean differences.

Appendix F. Tree Response/NBI Scatter Plots

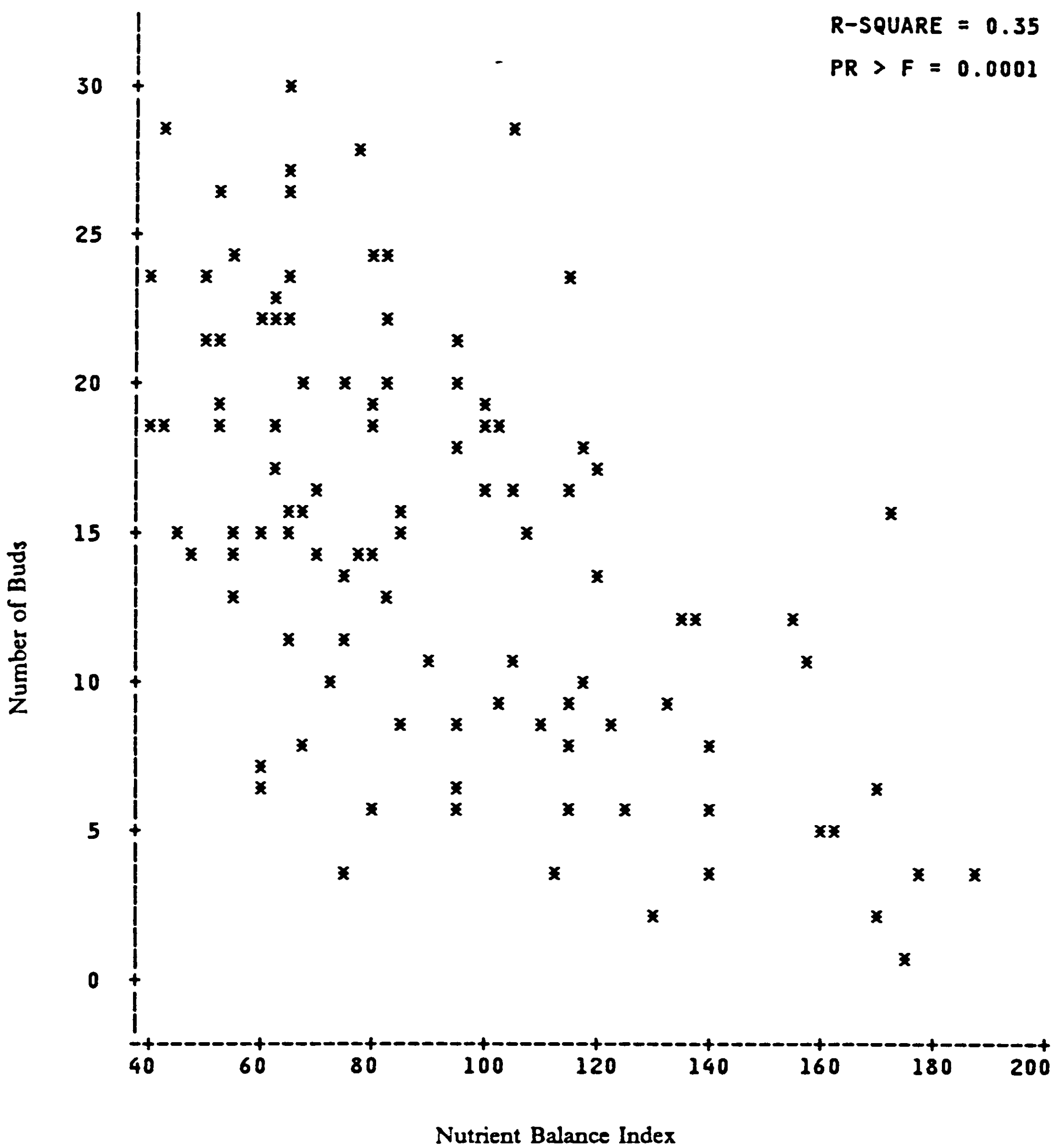
Appendix F-1

Scatter plot of leader length as a function of nutrient balance index



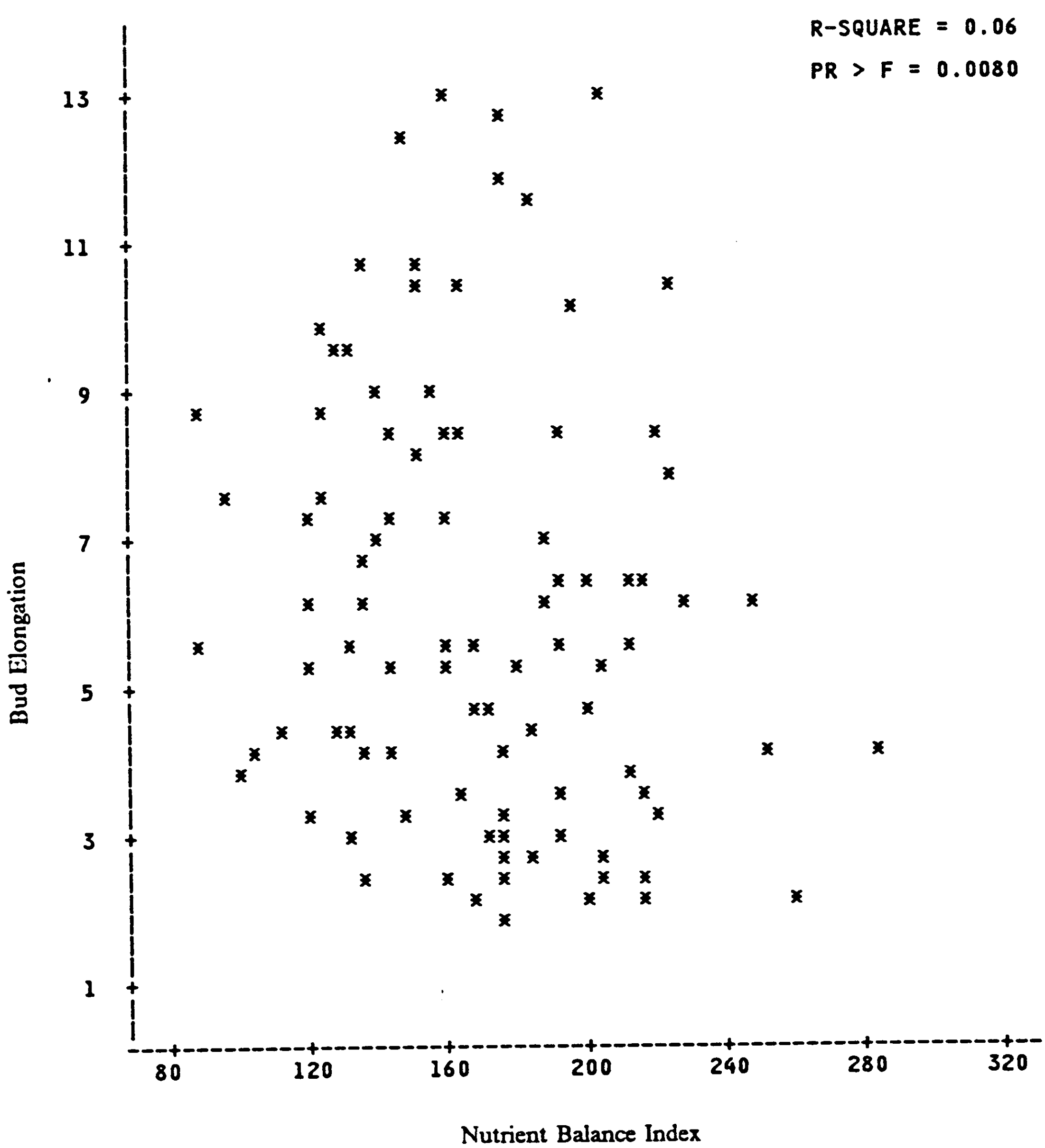
Appendix F-2

Scatter plot of number of buds as a function of nutrient balance index



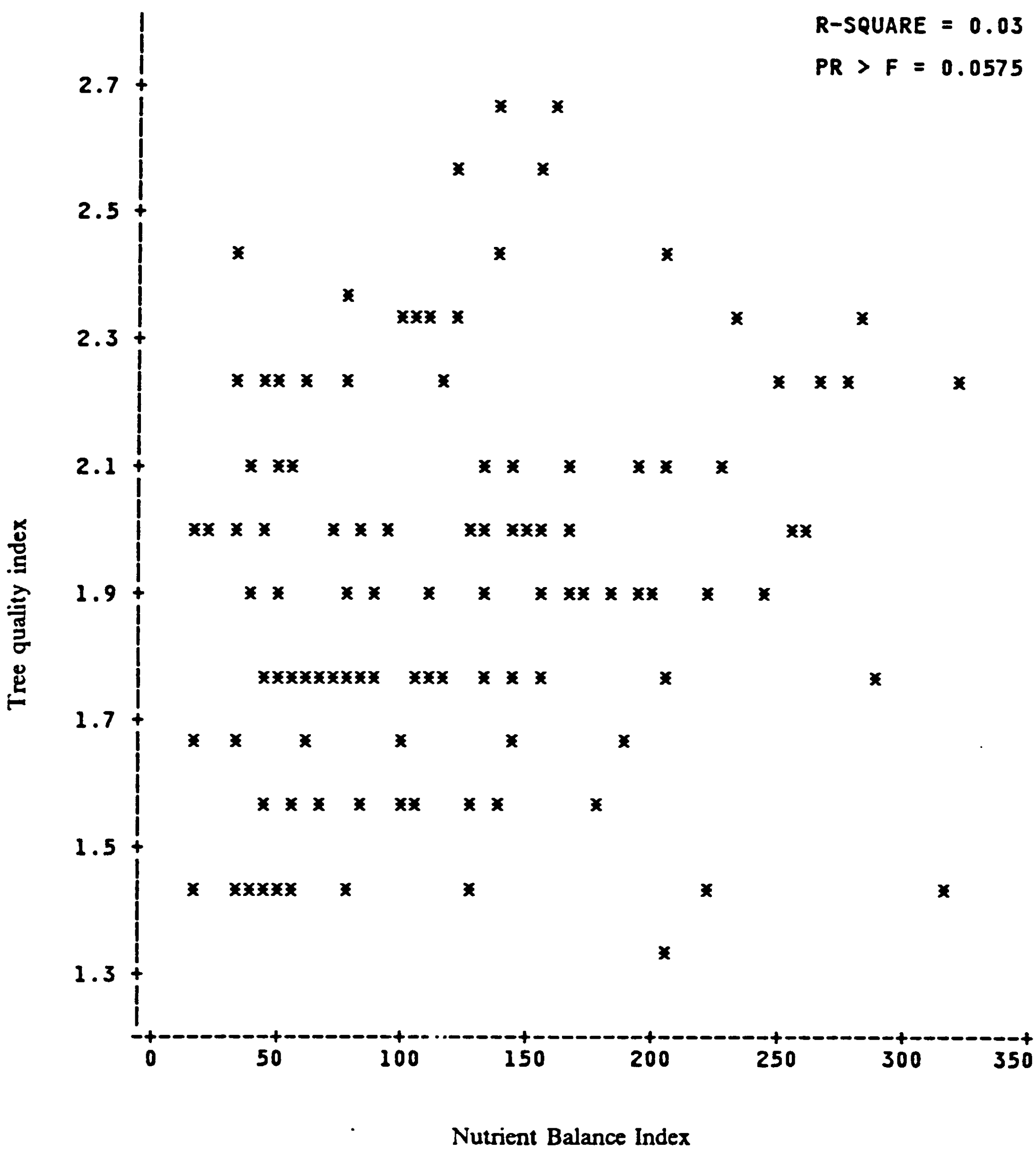
Appendix F-3

Scatter plot of bud elongation as a function of nutrient balance index



Appendix F-4

Scatter plot of tree quality index as a function of nutrient balance index



Appendix G. Tables of DRIS Diagnoses for LL, NB, BE, and TQ.

Appendix G-1

NB, DRIS indices, NBI, and foliar nutrient concentrations as affected by fertilizer treatments.

Plot No.	Fertilizer Treatment N	P	K	Ca	Mg	Number of Buds	DRIS Indices N	P	K	Ca	Mg	DM	Nutrient Balance Index	Nutrient Concentration N	P	K	Ca	Mg
	kg/ha/yr													%				
1	0	0	0	0	0	11	8	-9	-5	-5	14	-10	50	2.48	0.24	0.87	0.51	0.14
2	86	0	0	0	0	18	9	-16	1	-1	2	4	33	2.35	0.20	0.84	0.39	0.10
3	0	67	0	0	0	16	-6	12	-10	-17	14	-9	69	2.30	0.30	0.85	0.42	0.14
4	86	67	0	0	0	14	-4	1	-5	2	12	-7	31	2.31	0.26	0.87	0.58	0.14
5	134	111	87	0	0	23	3	5	-11	3	4	-2	28	2.34	0.26	0.79	0.49	0.11
6	134	111	87	982	491	18	-4	16	-16	-2	9	-7	53	2.31	0.30	0.78	0.51	0.13

LL, DRIS indices, NBI, and foliar nutrient concentrations as affected by fertilizer treatments.

Plot No.	Fertilizer Treatment N	P	K	Ca	Mg	Leader Length	DRIS Indices N	P	K	Ca	Mg	DM	Nutrient Balance Index	Nutrient Concentration N	P	K	Ca	Mg
	kg/ha/yr					- cm -								%				
1	0	0	0	0	0	11	2	-11	-11	11	20	-12	67	2.48	0.24	0.87	0.51	0.14
2	86	0	0	0	0	17	8	-16	-1	3	4	4	36	2.35	0.20	0.84	0.39	0.10
3	0	67	0	0	0	15	-8	13	-14	-3	21	-12	70	2.30	0.30	0.85	0.42	0.14
4	86	67	0	0	0	15	-11	-3	-13	20	19	-10	76	2.31	0.26	0.87	0.58	0.14
5	134	111	87	0	0	19	-1	3	-17	13	8	-3	45	2.34	0.26	0.79	0.49	0.11
6	134	111	87	982	491	15	-8	14	-23	11	15	-8	80	2.31	0.30	0.78	0.51	0.13

BE, DRIS indices, NBI, and foliar nutrient concentrations as affected by fertilizer treatments.

Plot No.	Fertilizer Treatment N	P	K	Ca	Mg	Bud Elong.	DRIS Indices N	P	K	Ca	Mg	DM	Nutrient Balance Index	Nutrient Concentration N	P	K	Ca	Mg
	kg/ha/yr													%				
1	0	0	0	0	0	3	5	-15	-5	5	21	-18	69	2.48	0.24	0.87	0.51	0.14
2	86	0	0	0	0	5	9	-19	5	-2	4	4	44	2.35	0.20	0.84	0.39	0.10
3	0	67	0	0	0	5	-8	9	-7	-11	22	-16	72	2.30	0.30	0.85	0.42	0.14
4	86	67	0	0	0	4	-10	-6	-7	13	18	-12	66	2.31	0.26	0.87	0.58	0.14
5	134	111	87	0	0	5	0	-1	-9	6	7	-8	31	2.34	0.26	0.79	0.49	0.11
6	134	111	87	982	491	8	-7	10	-14	4	15	-15	65	2.31	0.30	0.78	0.51	0.13

TQ, DRIS indices, NBI, and foliar nutrient concentrations as affected by fertilizer treatments.

Plot No.	Fertilizer Treatment N	P	K	Ca	Mg	Tree Quality Index	DRIS Indices N	P	K	Ca	Mg	DM	Nutrient Balance Index	Nutrient Concentration N	P	K	Ca	Mg
	kg/ha/yr													%				
1	0	0	0	0	0	2.2	6	-6	2	1	2	-1	18	2.48	0.24	0.87	0.51	0.14
2	86	0	0	0	0	1.7	16	-14	11	4	-6	13	64	2.35	0.20	0.84	0.39	0.10
3	0	67	0	0	0	1.9	-8	12	-7	-8	3	-12	49	2.30	0.30	0.85	0.42	0.14
4	86	67	0	0	0	1.5	-2	2	-2	7	1	-6	19	2.31	0.26	0.87	0.58	0.14
5	134	111	87	0	0	1.5	2	4	-3	8	-4	-2	23	2.34	0.26	0.79	0.49	0.11
6	134	111	87	982	491	2.0	-7	14	-11	3	-1	-11	48	2.31	0.30	0.78	0.51	0.13

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